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MINUTES
OF THE NINTH
EXPLOSIVES SAFETY SEMINAR, (1967)

NAVAL TRAINING CENTER,
San Diego, California,

15-17 August 1967.

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ARMED SERVICES EXPLOSIVES SAFETY BOARD
Washington, D. C. 20315

Host

DEPARTMENT OF THE NAVY

PREFACE

This is a record of the proceedings of the Ninth Annual Explosives Safety Seminar held at the Naval Training Center, San Diego, California, 15-16-17 August 1967.

The Armed Services Explosives Safety Board (ASESB) sponsors the annual Seminar as a means of providing an exchange of current information on explosives safety between those segments of Government and industry concerned with high energy propellants. Selected papers are presented by the participants during the course of the Seminar, and a free discussion of the subject matter is encouraged.

The material contained herein represents reports and opinions of the participants, and is a product of the individual or organization which he represents. The ASESB does not vouch for the accuracy of the facts presented, and does not necessarily endorse the opinions expressed.

Rapid and widespread exchange of information concerning explosives incidents and accidents is a vital component of a cooperative effort on the part of Government and industry to develop effective means of prevention in their safety programs. Questions and comments concerning the material herein should be directed to the individual speakers or their organization.

The Armed Services Explosives Safety Board, Nassif Building, Washington, D. C. 20315, should be advised of errors or other corrections that may be required in the text.

Appreciation is expressed to all participants for their interest, and their active role in promoting the cause of explosives safety within the Department of Defense and in the industries represented at the Seminar.

R. E. Johnson

R. E. JOHNSON
Captain, USN
Chairman, ASESB
1 November 1967

TABLE OF CONTENTS

Minutes of the

Ninth Annual

Explosives Safety Seminar

Naval Training Center

San Diego, California

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Armed Services Explosives Safety Board
Nassif Building
Washington, D. C. 20315

CAPT. RICHARD B. JOHNSON, USN
CHAIRMAN
ARMED SERVICES EXPLOSIVES SAFETY BOARD

As spokesman for the Armed Services Explosives Safety Board, I welcome you to this Ninth Annual Seminar. I trust that the program offered will be worthy of the interest you have shown by coming here.

The general program, all to be held in this auditorium, will concern topics believed to have wide interest to those having explosives safety responsibilities. This year for the first time we have arranged a half-day of specialist sessions, which will treat segments of the explosive safety problem that are of the greatest importance, but may be of special interest to only part of you. We hope that from the variety offered each of you will find one of special interest.

Our host for 1967 is the Navy. We are honored by the all-out effort which has been made to make our meetings comfortable and efficient. Within the Navy Department the primary sponsor is the Naval Ordnance Systems Command represented here by Capt. J. P. Jamison and Mr. Herb Roylance. The San Diego representative of the Ordnance Systems Support Office, Pacific is Mr. Jessie Green.

Here in San Diego we are jointly hosted by the Commandant of the 11th Naval District and the Commander of the Naval Training Center. RADM Brandley is represented by LCDR Joe Hudson whose primary duty is District Ordnance Officer and District Security Officer. CAPT. Ralph Lockwood of the Naval Training Center assigned LT Cathey as his coordinator.

I know all of you join me in thanking our hosts for their most gracious welcome and their labors in our behalf.

Our keynote speaker is a distinguished officer of the Navy whose career has been, and is, intimately associated with weapon acquisition and employment and with the attendant explosives safety problems. In recent years he has served as a Carrier Division Commander and as the Chief, Bureau of Naval Weapons. He is presently serving as Commander Naval Air Forces, U. S. Pacific Fleet. It is my honor to present VICE ADMIRAL Allen M. Shinn.

VICE ADMIRAL ALLEN M. SHINN, USN
COMMANDER NAVAL AIR FORCE, U. S. PACIFIC FLEET

It's a pleasure indeed to be here and speak to this group of professionals on the subject of explosives safety. I certainly do not consider myself a professional in this field, although Red Johnson and I did get initiated into some of the problems when I was in the Bureau of Naval Weapons a few years ago - in fact, when I began my Bureau career there. So I really consider it a privilege to be here and speak to a group of professionals such as you - including Mr. Henry Marsh, one of the grand old men of Explosives Safety and the entire weapons field.

Red and I were chiefly concerned with shore installations during my early Bureau career, in other words, explosives safety distances and radii, and how we could get the city of Concord, California to build a golf course outside of our ammunition depot instead of building some highrise apartments there; and how we could get the Bishop Estate to continue raising sugar outside our ammunition depot in Oahu instead of selling it off for real estate - that kind of thing. Real estate acquisition - which certainly is a very important problem when you think that if we don't defend our outloading areas and our storage areas by the appropriate kind of real estate acquisition, and if we do permit the development of residential high density projects nearby, we eventually lose the use of our major facilities. Concord and Bangor are the only outloading facilities for major weapons shipments to support any operation in the Pacific. Most of the Army, Navy, and Air Force weapons used in the Pacific have been shipped out of Concord, and a lessor amount, out of Bangor. There are no Army and Air Force outloading points on this coast, as all of you probably know. And Seal Beach, the Navy one that services the fleet down here in the Southern California area is not adequate for major trans-Pac shipments. So that kind of concern with explosives safety - the problem of acquiring real estate and building on it appropriately, is a major one which I first got involved in.

Later on, I was in the Plans and Programs part of the Bureau, in which we became concerned with weapons design and performance; what is each of these weapons going to do? how will it perform? whether its handling procedures, technical data, and such matters, that is, the weapons themselves rather than where they're stored and transported. Explosive safety here is of a different kind, of course. Its a matter of design and maintenance procedures.

Still later, I became Chief of the Bureau of Naval Weapons, and then I presided at its dismemberment into the Air Systems Command and the other Systems Commands. In other words, the dividing up into the Ordnance Systems and Air Systems Commands. I think it might be worthwhile in saying a word about that division to all of you who are involved in the weapons area, because we did make a fundamental change in the Naval organization at that time. The conclusion (with which I fully

concurred) was that we ought to keep in the Air Systems Command, not only aircraft and aeronautical material as it had been previously known, but also air launched weapons, complete, so that we kept together the parent aircraft and the weapon it was going to launch. Not only from the point of view of performance but also from the point of view of safety, it is essential that this be done, I believe. You can't treat the air-launched weapon separately from its parent launching and control system. And if those are separated into different organizations, if you break apart the weapons system at some arbitrary point where it falls off the rack, or someplace else in the aircraft structure, you get interfaces that do bring in performance problems and safety problems. I think we have the correct system for design and procurement of our air-launched weapons; and now that I'm out here in the fleet there may be some poetic justice in the fact that I have to operate and use the weapons that I was responsible for designing, back there in the Bureau and the Air Systems Command. So, I'm stuck with the problems that I created.

This is, I think one of the healthiest parts of our Naval Materiel business. The operators today, who are complaining that the Bureau isn't producing what they need, will maybe tomorrow be back in the Air Systems Command responsible for producing it. And those who are back there producing things will tomorrow be out here responsible for their operation. This kind of a "full-life-cycle" management and responsibility is, I believe, most important. Of course, you can't churn people around over this full life cycle too rapidly or you lose continuity. But rather than having one organization that's always involved with design or procurement, and another that's always involved with operations and maintenance, and a sort of wall between them, I feel the full life cycle plan with people circulating around thru the organization, is considerably better. When the Fleet states a weapons requirement, it goes back through the Commander-in-Chief to the CNO for a decision as to what it is the Navy needs. Then the CNO goes to the CNM and the Air Systems Command to design what the Navy needs, and the Air Systems Command goes to industry and gets bids and proposals and procures the weapons as they best meet the specifications set down by the CNO. Then, they are delivered by the Air Systems Command, stored and transported by our Ordnance Systems Command (we only have one storage and transporting organization, that's the Ordnance Systems Command) and then they are maintained in the Air Systems Command and Naval Air Force Pacific facilities and organizations here in the fleet, and of course finally employed in Naval Air Force Pacific ships in the various operating Fleets and Task Forces. That's the flow of responsibility in the full-life-cycle organization.

Ever since the advent of gunpowder, there have been longstanding problems regarding weapons. If you're going to have something that blows up with a big bang it might do it at the wrong time. Misfires, flashbacks, explosions, and other hazardous events are inherent in the business. Explosives safety people are concerned with minimizing these

hazards, as all of us are. Of course you can load a weapon with so many safety features that it becomes ineffective. You actually have more safety devices than you can handle. You get beyond a break-even point. This is an essential consideration in any safety device whether it be explosives safety or otherwise.

I think that it is worthwhile pointing out, with some pride perhaps, that the weapons we're using in Southeast Asia today are, in the main, Navy-developed weapons. The air-to-ground tactical warfare weapons bag that we have, i.e., Shrike, Walleye, Sidewinder, Sparrow, Zuni, low-drag bombs, Snake-eye, I could name several others. This speaks well for the overall results of the Naval air weapons effort and I think it also points to the fact that the Navy kept more active in the tactical air-to-ground field than perhaps the Air Force did, while they were concentrating on nuclear and strategic delivery. This of course is a war that requires the smaller tactical weapons. But they are being used in tremendous quantity and the last year of my incumbency in the Bureau of Naval Weapons, when the old Bureau was together, with air launched aircraft as well as ship launched weapons we spent about 8½ billion dollars - or we obligated that much - which is a pretty large piece of business - mainly because our tactical aircraft and tactical air weapons were being used by other Services and other countries in large numbers.

And, incidentally, in speaking of the organization I did not mention and emphasize, as I should, that embracing within the Air Systems Command the entire airplane and the air-launched weapons business, we set aside and took out of what had been the Bureau of Weapons all surface-and sub-surface-launched weapons. They are in the Ordnance Systems Command.

There's one point that I think is well worth mentioning that effects explosives safety as well as performance (and I guess all of the things that I'm talking about are interlocked between performance and explosives safety). That is the proliferation of weapons systems. All the new weapons that people want to use. Nowadays we can invent just about anything, yet there are limits to what we can support - clear-cut limits to the number of weapons that we can safely and effectively handle in the field or in the fleet. Unless a weapons system has a real advance over something that's in use already, or fills an absolutely new need that didn't exist before, we shouldn't burden the operating forces with a new weapon system requiring different techniques for its maintenance and performance and for its safety. There are break-even points here. There are limits beyond which you can't burden the operators, or they will make mistakes.

Explosives Safety aboard a carrier is probably one of the most critical areas of explosives safety in all of our Armed Forces. I think all of you realize that after reading about the ORISKANY's explosion almost a year ago and the FORRESTAL's just in the last weeks. Those of us in carrier aviation feel these very keenly, and I particularly feel the FORRESTAL tragedy because she used to be my ship. I commanded her

some ten or twelve years ago, and its like burning down the old homestead. In any case I think its worth reviewing these two incidents very briefly to point out some of the factors involved.

In ORISKANY it was a MK 24 parachute flare that caused the trouble. One of them went off during routine handling procedures while stowing it back into a locker. A chain reaction took place and did a lot of damage and cost a good many lives. We've taken steps to improve procedures and improve stowage spaces. First off, we've got a safer stowage; we moved the ready service locker from the hangar deck, where it was, up to the flight deck and gave it a blow-out bottom that would go over the side if the flares in the locker did all catch fire, and therefore would not create an explosion inside the ship which is what occurred in ORISKANY. And there are also mechanical jetison arrangements built into the locker so it can be released and dumped over the side. So our pyrotechnics ready service locker stowage is safer, and we've closed the barn door after that particular horse was stolen. This is a field of ship design in which explosives safety no doubt should have been more carefully considered, more explicitly laid out, and rules for stowing these flares and what kind of stowage they were to have should have been better defined before the ORISKANY fire. At least we've benefited by it, in hindsight. Also, on the MK 24 flare, there was quite a handling evolution involved here due to shortages of flares. The fact was that you had to bring them back aboard and re-use them; you can't always just jettison them - if you don't expend them in actual service use. They were being brought back aboard, restowed, and the evolution was quite complicated. There was a banding and taping procedure and securing the lanyard so it wouldn't whip around in the windstream, etc. I see that you're going to discuss MK 24 flares in your second agenda item, so I shan't go into the details of this, but it suffices to say that we had a kind of Rube Goldberg operation. Now we have a new dispenser coming out which will dispense the flare from the dispenser directly, and we don't have to have this banding, taping, and other associated problems. We hope that we will have a safer operation as a result, and I think we shall. Again, with respect to explosives safety and the design of the weapon, people should think ahead and see how the weapon is going to be used. Is it going to be used repetitively? carried repetitively? offloaded? downloaded? re-stowed? or is it always going to be fired off, once you get it out of the locker in its original container? If you have this repetitive operation, you have quite different safety procedures involved for use of that particular weapon.

I'd like also to say that we're developing a new flare, Brighteye, but I fear that we may have in it a basic error that we had in the MK 24, which is that the fuze and the main charge are installed together. In other words, we haven't separated the initiating charge from the main pyrotechnic candle, and this of course creates a much more dangerous situation than when you have fuzes stowed separately from the main charge, as we do in our explosive weapons. That is a rather basic, old-fashioned ordnance rule, and I don't know technically why we can't do it with flares; but there seems to be some reason. If its a valid reason, we're going to

have to continue to handle flares in quite a different way from other explosives.

Now we had the FORRESTAL affair and an even worse record of damage and lives lost. We are investigating that now. I don't know exactly what happened. The very brief outlines are that, in some way, a rocket in an armed group of airplanes went off and went thru the fuel tank of another airplane and set it afire which in turn set off some high order explosions of large bombs. That much I think is fact. What else happened, the investigating board is trying to determine. Well, what's involved in the way of explosives safety? First off, the safety devices used to ground out the rockets may not have worked in this case. Or if they did, there may have been personnel error involved someplace in their employment, or in employment of the rest of the weapons system in the airplane in the cockpit. The very best safety devices are essential in carrier aviation, they are essential anywhere, but in this particular case where you have a lot of airplanes all armed on the flight deck of a carrier, the safety devices on which people are depending to keep the system from firing until a conscious act to do so is taken, must absolutely be beyond question. Our procedures again have to be the very safest possible under the operating conditions that are imposed upon us. This is a consideration for explosives safety experts in the way of design and perhaps in working with the problem they will have ideas. If any of you have ideas which would be helpful they would certainly be welcome contributions in improving our safety. The very major thing which occurred in the FORRESTAL and one that I think all you explosives safety experts ought to put your minds to and shoulder to the wheel right now, is the question of how long it takes a weapon to cook off and create a high order explosion in a fire such as you're likely to have when jet fuel is burning around an airplane that's loaded with a bomb? This was where the FORRESTAL disaster really got out of hand, because once a 1,000 pound bomb explodes underneath an airplane about a foot off the flight deck it puts a hole in the flight deck, and that puts the fire down into the hangar with burning fuel going thru the whole area of the ship above the hangar deck.

I think it is of interest and value to note that the basic ship design in the FORRESTAL certainly stood up as planned. The flight deck has a couple of inches of armor, which was planned to turn a Kamikaze or glancing bomb or shell, or to explode one that was piercing and retain the explosion above the hangar deck - where you've got about 5 inches of armor. This was a real acid test for that kind of a design and it worked as planned. The explosion and fire and everything else were contained above the main (hangar) deck level and the ship propulsion, communications navigation, steering, etc., all remained intact. But that's a hellofa way to find out that the ship design was good.

We don't have, as far as I know, any empirical data, perhaps it would be very hard to develop, but we don't have any empirical data on cook-off time for our bombs. Of course, the design of the bomb is going to have quite a bit to do with that. Whether or not its a thin-skinned bomb, GP,

like the M117 which is one of those that exploded, or a fairly thick-skinned bomb more like our low drag MK 80 series. In other words, the packaging is going to have quite a bit to do with the cook-off time, as is the kind of filler. And I guess also the fuzing, because any part of it cooks off and actuates a fuze, the thing is going to blow up. But the cooking off of the main charge as well as the fuzing device, I believe, should be something that we test empirically. At least we will then know what kind of time we have involved to put out a fire in a case like that. And if we're introducing weapons that don't give adequate time to get the fire out, we've got to change the design. There I would say is a very fine challenge for the explosives safety profession, right now, to determine characteristics as to how soon a bomb will blow if subjected to jet fuel fire, and how to increase that time by better design. I recognize the difficulties in the very many different situations that may occur, but certainly two or three typical situations might be postulated and actually tested.

In the whole area of explosives safety there is one great problem and that is the flow of information, the flow of information in all directions! I'd start out with the people who have troubles with explosives safety in the fleet. I don't think we provide as well for the passage of technical information on out to where it can be used as well as we do in the aeronautical system. Also, the aeronautical system has developed means of reporting unsatisfactory and defective material, aircraft accidents, incidents, whatever you call them, even the so-called Any Mouse and his "hairy tail," anonymous incidents, things that have "almost happened to me" which are reported anonymously and therefore don't get anybody into trouble. We've done that for many many years in aeronautics. The ordnance incident or near incident or near accident isn't as well reported up thru the chains to where action can be taken on it. We have to work on that. I don't know whether this applies in other Services, but it certainly does in the United States Navy. I don't think we report our ordnance problems and close calls nearly as well as we do those that involve aircraft safety. The more information that comes in on this, the better the action that should be possible by those responsible for it. The information has to go in the other direction too, and again I don't think we've done as well in putting out the technical information concerning the safety and handling of our explosives as well as we have concerning the safety and handling of our aircraft and aeronautical material. Why this is true I'm not quite sure but I am sure that it's a fact. And this of course goes right back to industry because many of our safety bulletins come from our prime contractor in the aeronautical game. I don't think we get nearly as many out of the ordnance industry or the weapons industry, or the same feeling of responsibility perhaps as we do out of the aeronautical industry. I'd like to underline this because I think all of us can do a much better job in getting clearer, more concise and accurate technical instructions, a better organized system for distributing them.

I would like to remark here on something that impressed me all of the time that I was back there as the Chief of the Bureau of Naval Weapons. Having been an aviator and gone into this Bureau I really wasn't very much aware of how Ordnance business was done as compared to the way Aeronautics business was done. And the difference kept striking me right between the eyes as I tried to administer that large amorphous organization called the Bureau of Weapons. If you think back on it, you can see why things were the way they were, and of course they're changing. Ordnance developed as an important thing during the 19th century when we did not have an industrialized America and certainly didn't have an ordnance industry to turn to. Therefore, it was quite natural that ordnance developed the arsenal or government-depot concept for development and procurement of ordnance. And this has followed right on thru to some extent to the present day, very strongly up until recently. Aeronautics, on the other hand, came along at a time when we had an industrialized America and a very lusty and growing aircraft industry. Therefore, it was quite natural for the Government to turn to industry to develop and produce the flying machines that we needed. Moreover the flying machines that were first needed for commercial purposes, for the Army, and for the Navy were all about the same kind of a flying machine. There wasn't a great deal of difference. The differentiation came as the industry and the use of the flying machine developed. So we developed the prime contractor type of design, development, and procurement for aeronautics. We told an airplanee manufacturer that we wanted flying machines that would fly so far, so high, and so fast and have some other characteristics and then allowed two or three of them to compete and see what they could do towards building them. Not so in ordnance. We did the design work up in the loft at the Gun Factory and put out a very detailed specification to industry and said "build this to print and furnish me exactly what I've told you to build here on this blueprint and specification." Then the Government took the responsibility of putting together all the bits and pieces that were built to print, into a complete weapon, which hopefully would be useful. Due to this fact and also due to the fact that ordnance is produced in larger quantities, not brought back for maintenance but is expended, we have been forced (or maybe we wanted to anyway) to competitive procurement for ordnance, so that one manufacturer will be building it one year and another the next year, etc. If we put together the lack of a prime contractor system, with the competitive shopping around as the thing is built year after year, I think you can see where it would be very hard to get industry as much interested in and feeling as responsible for the design, performance, and safety of their individual product as for example in the F4 and McDonnell Aircraft Co. They build the F4 airplane and always will, and they have much more of a paternal interest in it than this year's producer of 20mm bullets has. I don't think that we can avoid this situation entirely, as between airplanes and 20mm bullets, but somewhere in between for most of our air weapons is, I think the proper way to go. While I was Chief of the Bureau I certainly pushed things as far as I could toward the prime contractor responsibility for a weapon system or a weapon, just as we have been doing for a long time in regard to the aircraft. I think its the right way to go. Instead of having 57

different contractors putting together bits and pieces of the MK 57 mine (I think we had the MK 57 mine in almost that many contractors' hands), we should have someone build the mine and bear all the responsibility for its performance and for its safety. Again, looking at the differences between ordnance and aeronautics, the old-fashioned ordnance was put aboard ship and the ship sailed away and the crew of the ship undertook the entire training and maintenance problem. The "School of the Ship" took over; therefore, the Bureau of Ordnance (now the Ordnance Systems Command) didn't feel the same kind of responsibility for providing maintenance equipment, training, etc. as did BuAer in the aeronautical business, where the weapons system never became fully ship based, but always had one foot ashore on an air station and one foot ship-based at sea. Therefore, in aeronautics we early developed a very good training and maintenance system ashore. We have a Technical Training Command, a Pilot Training Command, a Reserve Training Command. Training was recognized from the outset. In fact, until very recently, we had differences in the way we financed training equipment as between aeronautical and ordnance. In the aeronautical equipment, if we made a new buy, we bought equipment for training and the training devices at the same time, to keep people safe in its operation and in its employment. Until very recently we didn't in the ordnance world make that kind of a buy and provide for the training in the new ordnance equipment when we bought it. I think this is absolutely essential if we're going to stay safe in the explosives safety area, and we are doing it now in the present Air Systems Command. This again was a very clear-cut difference in the way that people traditionally looked at aeronautical equipment on the one hand and ordnance on the other.

I think that one of the advantages of the Bureau of Weapons, one of its contributions to the development of affairs is that it brought together in one organization, these two quite different ways of designing, developing, procuring, maintaining, and training. And made people look at the differences and decide which was the better way to go, or are there really reasons for maintaining different schemes with respect to aeronautical equipment and weapons. In some cases of course there are: they are not the same material, and they have different problems; but in many cases I think we profited by bringing together the two processes far more than they were in prior years.

The explosive safety profession both in Government, in-house military and civilian, as well as in the industry part of the Government-industry team deserves a great deal of thanks and appreciation for what they have done. Not only in performance, but in safety. When you stop to consider the mass of weapons that are used and the relative infrequence of incidents of the kind that I dwelt on today, we are doing a very very adequate job. I'd say in many cases its outstanding. Nevertheless there are these weak spots, there are these holidays in the business, and as all of you know, one weak point that causes a small explosion, that causes a bigger one, can be a terrific tragedy and we've got to work on each and every one of these weak links in the chain. Through design, procedures for handling, stowage, and all the way along. I want to thank you very much for what

you've done; I want to say that there's more to do. And perhaps the most important thing is to do everything as well as we know how to. Here I want to tell a story which illustrates this fact. The development of new technical data, more of it, new instructions, etc., won't solve the situation unless we really do everything as well as we know how, and I think we can improve things right from the present - using the information that we have.

There was an old farmer up in Pennsylvania, and he was working around the farm one late fall afternoon, when he had a visitor from the Agricultural School, a recent graduate, in the State Farm Extension Service. This young graduate was charged with going around and interviewing farmers and teaching them the latest methods of farming. How they could do things better and make more money. The old gentleman was quite friendly to the young man and allowed him to lead him all over the farm and show him where he could have done better about terracing the land, so it wouldn't wash away, and how he could rotate his crops so he would get more production, and do better fertilizing, and rebuild his hen houses so that the chickens would do better, and rebuild the pig pens and the stalls and all that kind of stuff. Better water sanitation, and all those things.

Well, this went on for quite a while and finally the sun was setting over the hills, and the farmer said "young man, I have got to go along now, somebody has to milk them cows, and I guess its me. I sure do want to thank you for all this information you've been giving me. Its real interesting. Like as not there's a lot of truth in all them things that you've been telling me. But you know, the real problem is that I don't farm now half as good as I know how to." And I'm afraid that in explosives safety we don't always farm as well as we know how to. And that's the first thing we have to do. Thank you very much, gentlemen.

Bruce M. Docherty
Assistant General Counsel, Department of the Army

Each year the Armed Services Explosives Safety Board has asked the General Counsel of the Army to make an attorney available for attendance at its Explosives Safety Seminar on High Energy Propellants. Those who have attended prior Seminars are probably aware of the reasons for attendance of counsel. I will restate those reasons briefly.

It has long been recognized that information and advice obtained through activities such as this Seminar are beneficial to the operations of the Government. Consistent with that recognition certain standards have been prescribed to insure that committees and similar groups sponsored by the Government for the purpose of obtaining such information or advice shall function at all times in consonance with the antitrust and conflict of interest laws.

This Seminar is being conducted in accordance with the standards applicable to this type of meeting. It is felt, however, that since any such meeting as this is subject to the provisions of the antitrust laws, a Government attorney should be present as an added protection to the Government and to all participants.

I am not here to prevent the full and free exchange of information. That would defeat the purpose of the Seminar. The primary reason for my presence is to guard against the inadvertent consideration of any subject which might bring the Seminar within some aspect of the antitrust laws. This is not likely in view of the excellent manner in which these Seminars are always conducted.

The agenda has been prepared with a view to permitting free discussion of the topics to be considered. I will be present throughout the Seminar. If at any time I think we are getting into an area which might raise antitrust impiications, I will call this to the Chairman's attention so that any such discussion may be avoided.

I will also be available for the consideration of antitrust, conflict of interest or other legal problems which may arise. I should add that I have always greatly enjoyed these Seminars and that I am very happy to be back again today.

RECENT LEGAL DEVELOPMENTS

Bruce M. Docherty
Assistant General Counsel
Department of the Army

At the Seventh and Eighth Seminars I discussed certain of the legal consequences which may be expected to follow an explosion.[1] Thereafter in March of this year I gave a talk on legal aspects of safety affecting the Federal Government. That was at the Annual Conference of the Southwestern Regional Federal Safety Council, and copies are available here.

It may be of interest to look at a few recent court decisions tending to illustrate or develop some of the points made in those prior talks.

As you may recall many courts hold business or industrial concerns absolutely liable for damage caused by extra-hazardous or ultra-hazardous activities. These terms mean about the same thing. In other words, a company which carries on very dangerous operations may be legally responsible for injuries caused to adjoining landowners or other members of the public regardless of how carefully the work is performed. A California case, decided in January of this year, illustrates this viewpoint.[2]

This was an action to recover for damage to plaintiff's real estate. Plaintiff claimed damage because of vibrations from a static firing rocket motor test conducted by the defendant Company under a contract with the United States Government.

At the trial the plaintiff was nonsuited. This meant that after hearing plaintiff's witnesses the trial judge thought that plaintiff's case was not strong enough to support a verdict in his favor. The trial judge therefore found against the plaintiff without hearing defendant's witnesses. The case was not submitted to the jury. The plaintiff appealed.

Plaintiff's evidence had been to the following effect.

In 1961 defendant Company wanted a site which would be suitable for testing rocket motors. It acquired 9100 acres in a valley. The area was generally undeveloped but a ranch owned by plaintiff was surrounded on three sides by defendant's land.

In early 1962 defendant tried to buy plaintiff's ranch. Defendant's lawyer was said to have told plaintiff that "we have to have your land before we can test." Plaintiff would not sell however.

Shortly thereafter, in April 1962, defendant announced a scheduled test firing. A press release issued by defendant stated that the firing was not expected to produce ground vibrations outside the valley.

Plaintiff was concerned, and asked defendant not to go on with the test. Defendant's lawyer informed plaintiff that they could not stop the tests but that defendant would take care of any damage.

Defendant then test fired a 120 inch solid fuel applied research rocket motor of three segments, reputedly the largest solid fuel rocket motor to be test fired to that date. The item was manufactured by defendant for the Air Force and was owned by the Government at the time of the test.

The motor was mounted nose-down on three "thrust collectors" which were affixed to a concrete base imbedded in the ground. The test site was located approximately 7800 feet from the boundary of plaintiff's property. The firing lasted 132 seconds and created up to a maximum of 350,000 pounds of thrust.

Plaintiff was on the sundeck of one of his buildings at the time of the test. He felt a very strong vibration. Other witnesses described it as a rumbling similar to an earthquake, or as like an earth tremor caused by a heavy truck passing by.

Plaintiff's ranch was intended for use as a boys' camp. It had a very fine well which over the years had consistently produced high quality water. The well water was used for drinking, for a swimming pool and for other purposes. There was expert testimony to the effect that with this well in production the plaintiff's land was worth $206,000. Without this water supply the fair market value of the ranch was estimated at $60,000.

Immediately following the test, plaintiff inspected his property but could find no damage. Water which was being pumped into the swimming pool was clear. About 80 minutes after the test, however, the water became muddy. Plaintiff called the condition to the attention of defendant's counsel. Defendant's counsel was quoted as replying: "I don't know how we could have done it, but I can't argue with 80 minutes."

The defendant supplied plaintiff with bottled water, and hired a contractor to repair the well. The well could not be repaired however. Defendant then hired a well-digger to drill a new well on plaintiff's land. The new well produced water but it was not consistently drinkable.

The appellate court came to the conclusion that there was no evidence to show that the defendant Company had been negligent. There was nothing to show that defendant had not used due care in selecting the test site, constructing the test stand or in the actual conduct of the test itself. If the testing had not been hazardous in nature, such a finding of due care would excuse a defendant from any liability.

The Court observed, however, that defendant was engaged in an ultrahazardous activity. The Court felt, as many courts have felt, that anyone carrying on so dangerous a business should be responsible for damage caused, no matter how carefully he plans and supervises the work. The Court's own words are illuminating and I quote:

> "In these circumstances public policy calls for strict liability.... There is no basis, either in reason or justice, for requiring the innocent neighboring landowner to bear the loss. Defendant, who was engaged in the enterprise for profit, is in a position best able to administer the loss so that it will ultimately be borne by the public."[3]

To phrase it a little differently, the court felt that damage caused to others by an unusually hazardous business activity should be treated as an operating expense of the business.

You may have noticed that the California court used the term "strict liability" in holding that defendant should be responsible in damages for any harm caused by the test. Other courts refer to "absolute liability." The terms have the same meaning.

Once the Court had decided that the rule of absolute or strict liability governed this case, causation became the most important question still to be decided. Even though there might be absolute liability--regardless of any fault on the part of the defendant--there could be no recovery by the plaintiff unless it could be shown that the testing was the actual cause of the damage.

At the trial plaintiff had introduced testimony by expert witnesses. Plaintiff's experts had testified that the test firing was the probable cause of the damage to the well and that the 80 minute interval before the water turned muddy was consistent with damage by vibration.

Moreover, while defendant had made no admissions of negligence the statement attributed to its lawyer "I don't know how we could have done it, but I can't argue with 80 minutes" might be regarded as an admission that the testing had caused the damage.

The appellate court felt that the actual cause of the damage was a question of fact which should be determined by the jury. You will recall that after plaintiff had given his evidence the lower court had decided the case without submitting it to the jury for a verdict.

The appellate court reversed the judgment of the lower court. The effect of the decision would be to require a new trial at which both sides would present their witnesses. The jury could then determine whether defendant's testing had been the actual cause of the damage to plaintiff's land.

Perhaps we should observe at this point that it is sometimes quite difficult to convince a jury or a court that damage which becomes apparent right after an explosion was not caused by that explosion.

In this connection the appellate court referred to an earlier California case where defendant had used explosives for blasting, and plaintiff

sued for damage to his house. In that case plaintiff's witnesses testified that immediately following the blast, they noted that the house had moved on its foundation and windows had pulled away from their casings. Defendant then brought forward expert witnesses who testified that considering soil conditions and the amount of the charge used, it would have been scientifically impossible for the explosion to have caused the claimed damages. In that earlier case, however, an appellate court held the evidence sufficient to support a finding for the plaintiff.[4]

Suppose we return now to the recent California case we have been discussing. The test firing of the rocket motor raised still another legal point.

At the Seventh Seminar, in talking about the legal aspects of an explosion I referred to the doctrine of sovereign immunity. Under that doctrine the Federal Government is not liable to a person injured as a result of the carrying on of Federal activities--unless the Government consents to be sued.

In 1946 the Government gave its consent to be sued in certain cases. The Federal Tort Claims Act, which became law in 1946, permits those injured by the negligence of a Federal employee to sue the Government.[5] (Negligent acts causing injury to others are usually referred to as torts.) There is considerable doubt, however, as to whether the Tort Claims Act authorizes recovery against the Government in cases of absolute liability, that is, where the plaintiff is injured without fault of negligence on the part of any Federal employee.[6]

In the California case we have been considering the test had been conducted under a contract with the Federal Government. The Court, as we have seen, had found no proof of negligence--in other words no proof that the test had not been carried on with all reasonable precautions. Quite possibly, in the absence of negligence, the Government would not have been liable for the damage to plaintiff's property if the Government had done the testing itself. The defendant claimed, therefore, that, as a Government contractor doing Government work, it should be entitled to the same immunity as the United States.

The Court said "No"--at least not in the case of ultra-hazardous activities.

Suppose a contractor is doing non-hazardous work for some public authority, perhaps the construction of a highway. If he follows the government plans and specifications, and does the work carefully, he probably will not be responsible for damage which he causes to others. For example, in one case the fill from a highway embankment washed into plaintiff's pond. The contractor was not liable for the resulting damage.[7] The rationale might be that the work is necessary in the public interest. The Government would not be responsible for such damage if it did the work itself. Therefore the same result should follow if the Government has the work done by a careful contractor. This is the general rule.

The California Court, however, refused to follow the general rule in the case of hazardous activities such as rocket testing.

Even assuming that the Government would not be liable if it had done the testing itself, the Court felt that the contractor should not escape liability for any damage which may have been caused. The Court said:

> "As between an innocent adjoining landowner, and the contractor, we find no compelling reason for so extending immunity."[8]

Courts have gone both ways on this point. A few years ago a somewhat similar case came before the Iowa Supreme Court. A contractor used explosives in constructing a new lock in the Mississippi River. Plaintiff's home was damaged by the resulting vibrations. The work was being done under a contract with the United States and the contractor had not been negligent. The Iowa Court saw no distinction between hazardous and non-hazardous activity in such a situation. It held that inasmuch as the contractor was doing the work for the Government it was not liable for the damage caused by the blasting.[9]

To sum up as to the probable liability of a company which is carrying on ultra-hazardous work under contract with the Government. The courts are very likely to impose liability upon those who cause injury to adjoining landowners or members of the public through the use of explosives or other inherently dangerous substances. There probably will be liability in such cases even if a company is working on a contract with the Government.

When the defendant has the benefit of sovereign immunity persons who are injured through no fault of their own have no legal remedy. There has been considerable reluctance, therefore, to extend immunity to contractors working with dangerous substances even though the Government would not have been liable if it had done the work itself.[10] The courts are not unanimous, however, as to whether contractors should share the Government's immunity in doing hazardous work.[11] The result may vary depending on the state where the accident or explosion occurs.

I am speaking, of course, of injuries to those outside the contractor's organization. Injuries to the contractor's employees would normally be covered by workmen's compensation.

So much for contractor liability.

Now suppose that an employee of a contractor is injured on Government work. Even though he is entitled to workmen's compensation, he decides to sue the Government. The remaining cases which I will talk about are concerned with that situation.

One question comes up from time to time when a Government contractor is doing work of a hazardous nature. What effect do Government safety

regulations have on the Government's legal liability for injuries to the contractor's employees? A Federal case decided last December by the Court of Appeals, Second Circuit, may throw some light on this problem. While there was no explosion the case did involve an independent contractor doing work of a hazardous nature for the Government.

This was an action under the Federal Tort Claims Act. Employees of a Government contractor, or their representatives, sued the Government as the result of an accident on work being performed for the Government.

A construction company had been awarded a Government contract to modify the upstream guide walls and approach channels of a lock and dam on the Hudson River. The lock and dam were owned and operated by the United States.

A cofferdam was constructed by the company to provide a watertight working area for its employees. After some dewatering the cofferdam collapsed and several of contractor's employees were killed or injured.

There was a finding that failure to add extra bracing to the cofferdam--to enable it to withstand increased pressure after dewatering and excavation--was negligence, and the direct cause of the failure of the dam.

Since the work was being done in New York State, the Court followed New York law. This is in accordance with the requirement of the Tort Claims Act that the Government's liability is determined under the law of the state where the accident occurs.

As the owner of the property, the Government had provided a safe place for contractor's employees to work. If the premises had been unsafe, the Government might have been liable. But the defective cofferdam had been built by the contractor with contractor's own materials.

The work was inherently dangerous. The Government, therefore, might have been liable if a member of the public had been injured, since normally a person cannot escape responsibility for damage caused in the course of inherently dangerous work merely by having a contractor do it for him. Generally the ultimate responsibility for carrying on hazardous work carefully and safely cannot be delegated to anyone else. The contractor's employees, however, were covered by workmen's compensation and presumably the cost of workmen's compensation insurance had been included in the contract price and so in effect paid for by the Government. Since compensation had already been provided by the Government, there was no need to hold the Government liable merely because the work was hazardous.

The plaintiffs claimed, however, that the construction company was not really an independent contractor. They argued that the Government controlled the actual operations under the contract and so was responsible for any unsafe conditions.

The contract gave the Army Engineers broad supervisory powers. There was an accident prevention clause binding the contractor to follow the Corps of Engineers safety manual and any additional safety measures the contracting officer determined to be reasonably necessary. The contractor's superintendent had to be satisfactory to the contracting officer. There was a Government inspector on the project on a full-time basis. He had the authority to stop the work if an obviously unsafe condition was not corrected. The Government did, in fact, stop the work on one occasion until a hazardous condition was removed.

All this was not enough to establish Government liability. The Court found that the employees took their orders only from the contractor. The contractor, and not the Government, directed the day to day contract work. Government intervention in details was occasional only. Government intervention did not in fact cause the accident.

In effect the Court found that merely by setting up a safety program the Corps of Engineers did not undertake to check the technical safety of every detail of performance and prevent all accidents. The construction company was still an independent contractor directing the work of its own employees.

The Court gave judgment for the United States.[12]

There are two other cases I would like to discuss. Each involved an explosion in a contractor's plant.

In the first of these cases plaintiffs were employed by an independent contractor producing photoflash bombs as a subcontractor under an Army contract. The work was done on the contractor's own premises. The contractor used its own materials, though technically title to such materials had passed to the Government to secure certain advance payments.

Under the terms of the contract the Government had the right to make safety inspections. It did so frequently through its quality inspectors on the premises and through other inspectors who were sent in from time to time. If it was not satisfied with a safety condition the Government could withdraw its quality inspectors at that location. The Court found that the purpose of the Government's safety inspections was to protect contractor's employees as well as those Government personnel who were on the contractor's premises.

One morning there was an explosion in a small wooden building. It took place about 20 minutes after the regular morning inspection by the Government. Plaintiffs, who worked in the building, were injured. They sued the United States.

The plaintiffs claimed that the explosion was caused by dust and grit on some powder-filled relay cups. There was evidence of dust and grit in the air from carpenter work at the building that morning. Plaintiffs

argued that the Government's employees were negligent in permitting the contract work to continue under these conditions.

The plaintiffs were really invoking the so-called "good Samaritan" rule. Back in 1955 the Supreme Court had said "one who undertakes to warn the public of danger and thereby induces reliance must perform his 'good Samaritan' task in a careful manner."[13]

Plaintiffs were claiming that, having induced them to rely on its safety program, the Government had become responsible for their safety.

The Court found, however, that under the contract the responsibility for the safety of plaintiffs and other workers was placed on the contractor. Plaintiffs' employer had its own safety program. No Government employee had ever told the workers that the Government was responsible for their safety. Moreover, it was the employer's foreman--not the Government inspector--who told the employees that it was all right to continue work on the morning of the explosion.

Under these circumstances the plaintiffs could not reasonably have relied on the Government for their safety. In the absence of such reliance the Government had no duty of care, or responsibility for the safety of the contractor's employees.

The Court indicated further that under the Tort Claims Act the Government is liable only for negligence on the part of a Government employee. Since no such negligence had been shown the Government was not liable.[14]

The other case involving an explosion in a contractor's plant was decided by the Federal Circuit Court of Appeals for the Tenth Circuit in April of this year.

This was an action against the Government under the Federal Tort Claims Act. An employee of a contractor was killed in an explosion while performing research and development work on a solid fuel propellant under an Air Force contract. The employee was just entering a building containing highly unstable casting solvent used in the manufacture of solid fuels when the explosion occurred.

The plaintiff argued along these lines. The Government had directed the contractor to deal with inherently dangerous substances. Therefore, the plaintiff claimed, the Government had a duty either to provide adequate safety regulations or to see that the contractor followed adequate safety regulations.

The Court said "No." The contract provided for compliance by the contractor with certain specific safety regulations and with any additional safety measures required by the contracting officer. The Court held that this did not mean that the Government was under any duty to impose additional safety requirements.

As we have already observed, a person cannot usually escape responsibility for damage caused as a result of inherently dangerous work merely by having a contractor do the work for him. Ordinarily, however, a person making such a contract is not liable for injury to contractor's employees working in contractor's plant and covered by workmen's compensation.

Under these circumstances the Court regarded contractor as primarily responsible for the safety of its own employees.

The Court therefore refused to hold the Government liable for the death of the contractor's employee. The Court observed that in experimental work of this kind, there will probably be danger to contractor's employees no matter what precautions are taken.

Furthermore, the Government did not have control and supervision over contractor's employees. Such control and supervision were exercised by the contractor.

There was a judgment for the United States.[15]

It might be well to mention here that it would be much harder for the Government to escape liability for an explosion in a Government-owned plant even if the plant is operated by a contractor.[16]

Once someone asked me if the Government wouldn't be better off legally if it didn't prescribe any safety regulations when work is done in a contractor's plant? I think that is the wrong approach. Entirely apart from legal considerations it is clearly in the best interest of the Government to help prevent accidents on Government work.

Of course I am not attempting to pass upon the legal implications of particular safety regulations with regard to specific contracts. Such legal implications are a matter for your own counsel.

There are at least three situations, however, in which the Government would probably be liable to a contractor's employees injured in a contractor's plant. First, if the Government had taken over detailed direction of the work being performed by contractor's employees. Second, if Government personnel had given contractor's employees good reason to believe that they should rely on the Government, instead of on the contractor, for their safety. Third, if an employee of the contractor were injured as a direct result of the negligence of Government personnel.

I am not suggesting, therefore, that the Government will never be liable to an employee of a contractor who is injured as the result of an explosion in the contractor's own plant. What I do suggest is that the fact that safety regulations are written into the contract, and enforced by the Government, does not in and of itself make the Government liable to contractor's employees if an accident occurs.

Let me make one final comment on the legal aspects of an explosion. It is always difficult to predict the final result of a lawsuit whether brought against the Government or against a private concern. I think we should never lose sight of the fact that the best way to avoid legal liability for an accident is not to have the accident at all. And, as I said at the Conference of the Federal Safety Council, this is where the safety officer comes in. His job is all important.

References

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3. 56 Cal. Rptr. at 137

4. McGrath v. Basich Bros. Constr. Co., 7 Cal. App. 2d 573, 46 P. 2d 981 (1935)

5. 28 U.S.C. 1346(b), 2401(b), 2671-2680

6. See Dalehite v. United States, 346 U.S. 15, 73 S. Ct. 956, 97 L. Ed. 1427 (1953); United States v. Praylou, 208 F. 2d 291 (4th Cir. 1953), cert. denied, 347 U.S. 934

7. Valley Forge Gardens, Inc. v. James D. Morrissey, Inc., 385 Pa. 477, 123 A. 2d 888 (1956)

8. 56 Cal. Rptr. at 141

9. Pumphrey v. J.A. Jones Constr. Co., 250 Iowa 559, 94 N. W. 2d 737 (1959)

10. See Whitney v. Ralph Myers Contracting Corp., 146 W. Va. 130, 118 S. E. 2d 622 (1961)

11. See Pumphrey v. J. A. Jones Constr. Co., supra

12. Lipka v. United States, 369 F. 2d 288 (2d Cir. 1966)

13. Indian Towing Co. v. United States, 350 U. S. 61 at 64, 76 S. Ct. 122, 100 L. Ed. 48 (1955)

14. Richardson v. United States, (W. D. Tenn. 1966) 251 F. Supp. 107

15. Butsler v. United States, 376 F. 2d 634 (10th Cir. 1967)

16. See Martin v. United States, Civil Action 794, E. D. Texas, August 7, 1964, aff'd 354 F. 2d 686 (5th Cir. 1966)

FLASH FIRE PROTECTIVE CLOTHING

by

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During the development of solid propellants and manufacturing scale-up for use in large missile programs, the need for personnel safety for operating personnel became of paramount importance. This was forcibly impressed by the occurrence of incidents involving injury and even fatalities with operating personnel. Thiokol Chemical Corporation recognized this need and took action through facility design, construction and operating procedures to minimize exposure to personnel during manufacturing operations. Personal protective equipment was provided in the form of flame retardant clothing and eye protection. This was considered adequate until a small mixer fire involving a fatality occurred at the Elkton Division. Action was initiated to increase personal protection during certain hazardous operations, such as mixer scrapedown through the design and use of a flash suit fabricated of a reflective type material.

A one-piece suit with a hood type head piece was designed and fabricated from an aluminumized fabric with a plastic view plate. While this provided additional protection it was lacking in features of comfort, adequate vision, ease and speed of removal and ventilation. During this phase in development of the suit, another incident occurred in the Wasatch Division involving three fatalities during the scrapedown of a 300 gallon horizontal mixer. This made the need for such a protective suit a must for attended hazardous operations and the Wasatch Division took over its development from Elkton. An extensive design, fabrication and test program was implemented by Safety and resulted in a protective suit which has been in use better than one and a half years throughout various propellant process operations.

The following film depicting tests and test results should provide conclusive evidence as to its value in fire exposure.

(16mm film)

Manikin dressed in flame proofed cover alls and Flash Fire Protective Suit prior to test.

-Manikin engulfed in burning propellant - flame.

Manikin after test showing scorched areas on legs of coveralls.

FIRE EXPOSURE TEST

FLASH FIRE PROTECTIVE SUIT

Summary

On 6 and 7 January 1966 tests were conducted to determine the protection afforded by the use of a Thiokol-designed and fabricated Flash Fire Protection Suit. This suit, constructed of aluminized rayon fabric and equipped with a ventilated hood, was designed to afford protection for personnel engaged in operations involving materials (propellant) that generates extremely high temperatures and burns at flash fire rates. This report sets forth the tests conducted to demonstrate the capability of the suit and the results obtained. For comparative data, standard flameproofed coveralls were subjected to the same test environments.

Test Objectives

1. To determine the fire resistive and flame reflective qualities of the Flash Fire Protective Suit.
2. To determine the temperature differential at varying locations on the interior and exterior of the suit.

Test Dates and Location

6 and 7 January 1966 - Wasatch Division Burning Ground Area. The outside temperature was 42°F.

Test Samples

A. Flash Fire Protective Suit

1. Body - Three-quarter length smock, fabricated of 10-ounce aluminized rayon fabric, fastened at the back by metal snaps.

2. Hood - Modified welders hood frame equipped with a wrap-around Lexan face shield with an acetate cover shield. This hood is an integral part of the suit, sewn to the body and designed to be worn in the down or up position.

3. Hood Ventilation - Perforated ventilating ribs, constructed of avcoat insulation. Side ventilation ports. Opening covered with two screens 8 and 16 mesh zinc coated wire.

Total weight of the suit is approximately five (5) pounds.

B. Flameproofed Coveralls

Standard explosive industry coveralls treated with flameproofing solution.

Test Equipment and Material

A. Simulated 20-gallon mixer

B. TPH-1011 propellant, uncured - 240 pounds per test

C. Burning Ground Igniter

D. Iron Constantan Thermocouples

E. Continuous Electrical Recorder

F. Flash Fire Protective Suit

G. Flameproof Coveralls (2 pair)

H. Manikin

I. Plyboard Silhouette (human)

J. Motion Picture Cameras

Tests

Two tests were conducted as follows:

A. The manikin (simulated human) was dressed in flameproofed coveralls. The Flash Fire Protective Suit was placed on the manikin over the flameproofed coveralls. Thermocouple connections were made as follows:

1. Exterior of suit at front, chest high.
2. Inside the suit hood at face level directly behind the Lexan shield.
3. On the manikin, under the coveralls and suit, against the chest.
4. Under the suit on the coveralls at the back, waist high.

The human silhouette was dressed in flameproofed coveralls. No connections for temperature recordings were connected to the silhouette.

The manikin and silhouette were placed in upright positions 15 feet directly in front of the simulated mixer.

The simulated mixer was set up in the tilted position. Two hundred forty pounds of uncured TPH-1011 propellant was placed in the mixer. A Burning Ground igniter was placed in the mixer.

The propellant was ignited from a remote location. Motion picture coverage was obtained.

B. Test Two

The test arrangement for Test 2 was the same except the manikin and silhouette were placed 7 1/2 feet in front of the simulated mixer.

Test Results

A. Test One

The propellant burned for 61 seconds. Both test samples were subjected to external temperatures of 800°F. Small

pieces of burning propellant were projected from the mixer and struck the suit. The suit suffered only minor scorched spots from the projected propellant.

Of the three thermocouples located on the manikin under the flash suit, only one recorded an increase in temperature 3°F above ambient. No other evidence of fire or heat was noted.

The coveralls on the silhouette were scorched extremely but did not support combustion.

B. Test Two

Both test samples were completely engulfed in flame for 7.8 seconds. The manikin was pulled from the flame at this time to simulate an escape attempt.

The following temperature recordings were obtained from the thermocouples mounted on the manikin. These are expressed in degrees fahrenheit:

Time (Seconds)		Thermocouples Numbers (1)	(2)	(3)	(4)
0	Degrees:	42	42	42	42
1		478	45	42	42
2		813	50	42	44
3		912	60	42	52
4		960	75	42	73
5		1040	85	42	103
6		1005	90	42	140
7		1150	105	42	150
8		1480	125	45	150
9		1240	110	50	148
10		1120	105	55	145

Thermocouple No. 1, located on the exterior of the suit at the chest, recorded a maximum 1480°F. Thermocouple No. 2, inside the hood at face level, recorded a high of 125°F. Thermocouple No. 3, located on the skin of the manikin at the chest under the coveralls and suit, recorded a maximum of 50°F, an increase of 8°F above the outside temperature. Thermocouple No. 4, located under the suit on the coveralls at the back, recorded the highest temperature inside the suit - 150°F.

Several areas of the suit were badly scorched from direct exposure to flame. The exterior acetate shield (hood) was almost entirely consumed. No indication of scorching or distortion of the Lexan shield was evident. Visibility through the shield was good.

The coveralls on the manikin (under the suit) were scorched on one side. This is believed to have occurred when the manikin was pulled from the fire. Flame got under the lower portion of the suit. The manikin incurred no damage as a result of the heat or flame.

The coveralls on the silhouette were consumed by the fire except for a small area on the legs painted with a heat resistive paint. The silhouette was scorched over the entire surface.

Conclusions:

The data obtained and evidence of both tests show that a person properly dressed in flameproofed coveralls and Flash Fire Protective Suit has a high probability of escape from propellant fires and flash fires from other sources without sustaining serious injury.

The reflective qualities of the Flash Fire Protective Suit is shown by the temperature contents in Test Two, 1480°F on the exterior and 125°F at face level inside the suit, are excellent.

A comparison of the damages sustained by the silhouette dressed only in coveralls and the manikin dressed in coveralls and Flash Fire Protective Suit is a measure of the degree of effectiveness afforded by the suit.

Because of their effectiveness, as demonstrated in the tests, Flash Fire Protective Suits are worn by personnel when they enter mixer facilities during mixing operation, after premix addition and until the mixer is dumped and in the upright position. Flash Suits are worn by personnel who scrape down transfer hoppers during casting operations and other operations as deemed necessary by the Safety Department.

TESTING "NOMEX" MATERIAL AS HEAT

RESISTANT CLOTHING FOR INDUSTRIAL APPLICATION

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ACKNOWLEDGEMENT

Thiokol Chemical Corporation, Operating Contractor of Longhorn Army Ammunition Plant, Marshall, Texas, would like to take this means of recognizing the cooperation and assistance of the members of the Textile Fibers Department of the E. I. DuPont de Nemours & Company, Inc., Willmington, Delaware, for their technical and material contribution to this series of tests.

INTRODUCTION

There are two requirements to be considered when selecting apparel for use in a hazardous thermal environment. The first is that the clothing itself shall not contribute to the wearer's injury by burning, melting, or disintegrating in the presence of a high energy heat source. The second is that the clothing system act as a thermal barrier which will effectively protect the wearer for a given interval of time.

As a part of the continuing effort at Thiokol Chemical Corporation's Longhorn Division to give employees the best personal protection possible during the manufacture of "high energy heat source" munitions and rocket motors, a decision was made to test "Nomex" as a replacement for "flameproofed" cotton presently used as clothing material.

"Nomex" is a member of the "Nylon" family of fibers and was developed by E. I. DuPont de Nemours & Company, Inc. for applications requiring good dimensional stability and excellent heat resistance; the same basic requirements as stated above for use in a hazardous thermal environment.

"Nomex" has already been adopted by several military and civilian users for special applications, e.g., summer flying suits, the astronauts' uniform, U. S. Forestry Service uniform for fire fighters, etc.

See Appendix A, General Information & Data, for additional "Nomex" familiarization.

DISCUSSION

The objective of this series of test was to determine the best combination of protective clothing (utilizing "Nomex" material) that would afford the line worker optimum protection against incident conditions. The data was recorder and developed for a period of time up to fourteen seconds. The first three to five seconds, however, are the most critical.

TEST PREPARATION

Materials

A mannequin, test clothing, gloves, face shield, a flare pellet coated with Ignition Composition, thermocouples, lead wire, glass tape, oscillograph, photographic equipment, and two electric squibs for each test.

Clothing Combinations

The different combinations of clothing used in these test series are as follows:

Test Number	Clothing
1.	Seven ounce "Nomex" coveralls with no underclothing.
2.	Five ounce "Nomex" coveralls over four and three-tenths ounce "Nomex" underwear.
3.	Five ounce "Nomex" coveralls over seven ounce "Nomex" underwear.
4.	Seven ounce "Nomex" coveralls over four and three-tenths ounce "Nomex" underwear.
5.	Five ounce "Nomex" coveralls over "flameproofed" cotton coveralls.
6.	"Flameproofed" cotton coveralls over seven ounce "Nomex" underwear.
7.	Aluminized knee-length fiberglass coat over "flameproofed" cotton coveralls.
8.	"Flameproofed" cotton coveralls over cotton "T" shirt.

Instrumentation

Instrumentation consisted of ten iron-constantan and two copper plate/iron-constantan thermocouples located on the surface of the mannequin in designated locations (see Fig. 11). These locations remained fixed for each test so that a comparison of the degree of protection afforded in each test could be accomplished.

Thermocouples were located in the following positions on the mannequin:

Thermocouple	Location
1	Palm of right hand
2	Inside of right wrist
3	Front of right bicept
4	Right chest
5	Right side
6	Right thigh
8	Right chest - between inner and outer garments
9	Right chest outside of garments
10	Right temple
11	Right chest (copper plate/iron-constantan)
12	Right thigh (copper plate/iron-constantan)

TEST METHOD

Procedure

1. Attach thermocouples to mannequin in the designated locations. (Fig. 10)

2. Clothe mannequin for test and place in position with aluminum plate (to divert pellet when dropped) to similate escape of person from presence of heat source. (Fig. 11)

3. Connect thermocouple leads.

4. Attach pellet to palm of right hand with glass tape.

5. Attach shunted squibs to pellet and extend lead wires down toward right leg.

6. Check to verify that the instrumentation and camera are ready and firing circuit is open.

7. Make final connection of firing circuit and lead wires.

8. Ignite pellet.

Performance

A review of the film taken during each test revealed that when ignited, the pellet developed a fire ball approximately three feet in diameter. The glass tape used to secure the pellet to the hand retained the pellet for an average of 600 milliseconds. This would closely approximate the reaction time of an individual in a similar situation. The pellet dropped to the aluminum plate propped against the mannequin's leg and rolled away from the mannequin.

Evaluation

Heat transfer is measured in the units of calories per second over a given area (per square centimeter) and is referred to as heat flux. The heat flux which can be tolerated by human tissue has been studied by a number of researchers[1] and a typical curve of heat flux versus time to produce pain and blister is shown on Figs. 1 and 2. These curves, developed by the Navy, indicate the time to produce pain or second degree burn at various levels of heat flux. A high level of heat flux can be tolerated for only a very short time whereas considerably longer times may be tolerated with low levels of heat flux.

A copper plate/iron-constantan thermocouple and oscillograph was used to register and record the amount of exposure during the test. The temperature rise per second (°F) was calculated and plotted (Fig. 1) to determine the heat flux. The heat flux was then plotted on a heat flux versus time to pain and blister curve (Fig. 2) at one second intervals of exposure to determine the potential for tissue damage.

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1 Stoll, Alice M. and Greene, Leon C. "Relationship Between Pain and Tissue Damage Due to Thermal Radiation", Journal of Applied Physiology, 1959, 14(3):373-382

Buettner, Konrad, Ph. D., "Effects of Extreme Heat on Man, Protection of Man Against Conflagation Heat", Journal of American Medical Association, October 28, 1950, pp 732-738.

TEST RESULTS

Test 1 - This test was conducted as a feasibility test only and was not considered in the final analysis as suitable attire since the mannequin was dressed only in the seven ounce "Nomex" coveralls.

Test 2 - An examination of the mannequin after the test revealed that the five ounce "Nomex" coveralls developed a hole extending from under the arm pit and shoulder seam to about the middle of the thigh, and charred from the middle of the thigh to the knee. (Fig. 12 is typical of the pattern burned in five ounce coveralls.) The hole extended from the buttons in the center of the chest to a line under the right arm pit.

The "Nomex" underclothing under the coveralls had three badly scorched areas, one area approximately two inches in diameter on the chest and two on the right hip about the same size.

The heat flux vs. time to pain and blister threshold curve for this test (Fig. 3), indicates heat flux sufficient to cause pain and probably first degree burns.

Test 3 - The five ounce "Nomex" coveralls used in this test opened up identically to those used in Test 2. However, the seven ounce "Nomex" underclothing beneath the coveralls showed only light scorch marks on the outside of the material; these being in the area of the right chest and hip

The heat flux vs. time to pain and blister threshold for this test (Fig. 4), indicates that the heat flux did not approach the pain threshold.

Test 4 - The inspection following this test revealed that the seven ounce "Nomex" coveralls developed a hole in the area of the right chest approximately 5 x 9 inches in size. A charred area extended from the waist to the knee. (Fig. 13 is typical of the pattern burned in seven ounce "Nomex" coveralls.)

The heat flux vs. time to pain and blister threshold curve for this test (Fig. 5), indicates no approach to the pain threshold and consequently a burn would not have resulted.

Test 5 - The five ounce "Nomex" coveralls used in this test developed a hole identical to those developed in Tests 2 and 3, i.e. from the arm pit to the middle of the thigh and from the buttons in the center of the chest to a point in line with the arm pit (Fig. 12). The flameproof coveralls beneath the "Nomex" coveralls charred in the area of the right chest. The charred area was 11" long and 3" wide and was centered between the shoulder and the waist.

The heat flux vs. time to pain and blister threshold curve for this test (Fig. 6), shows an initial increase and decrease in the heat flux as the pellet is ignited and drops away. However, at 2.5 seconds, the flameproof cotton continues to smolder causing the heat flux to rise again. Although the coveralls continued to burn for several seconds, the heat flux did not approach the pain threshold.

Test 6 - During this test, the flameproof cotton coveralls flamed up and burned extensively on the right side and leg (Fig. 15). Although the seven ounce "Nomex" underwear protected the mannequin for approximately nine seconds, it finally charred through and the heat flux increased to a point beyond the pain threshold. This is shown the heat flux vs. time to pain and blister curve for this test on Fig. 7.

Test 7 - An inspection of the aluminized coat after this test revealed the coat to be blackened in the area of the right chest. The aluminized coating over the fiberglass appeared to have remained intact with the exception of a one inch strip across the right chest. (This is not visible in Fig. 17) At this point, the threads of fiberglass were visible; however, the underside of the garment remained intact.

The heat flux vs. time to pain and blister curve for this test (Fig. 8) shows the aluminized coat to be very satisfactory since the heat flux remained at a low value.

Test 8 - The flame proof cotton coveralls burned quite extensively in this test. They continued to smolder until extinguished as indicated on the heat flux vs. time to pain and blister curve (Fig. 9); the heat flux extends beyond the blister threshold.

A comparison of the temperatures recorded for each test at each thermocouple location is listed as Appendix B.

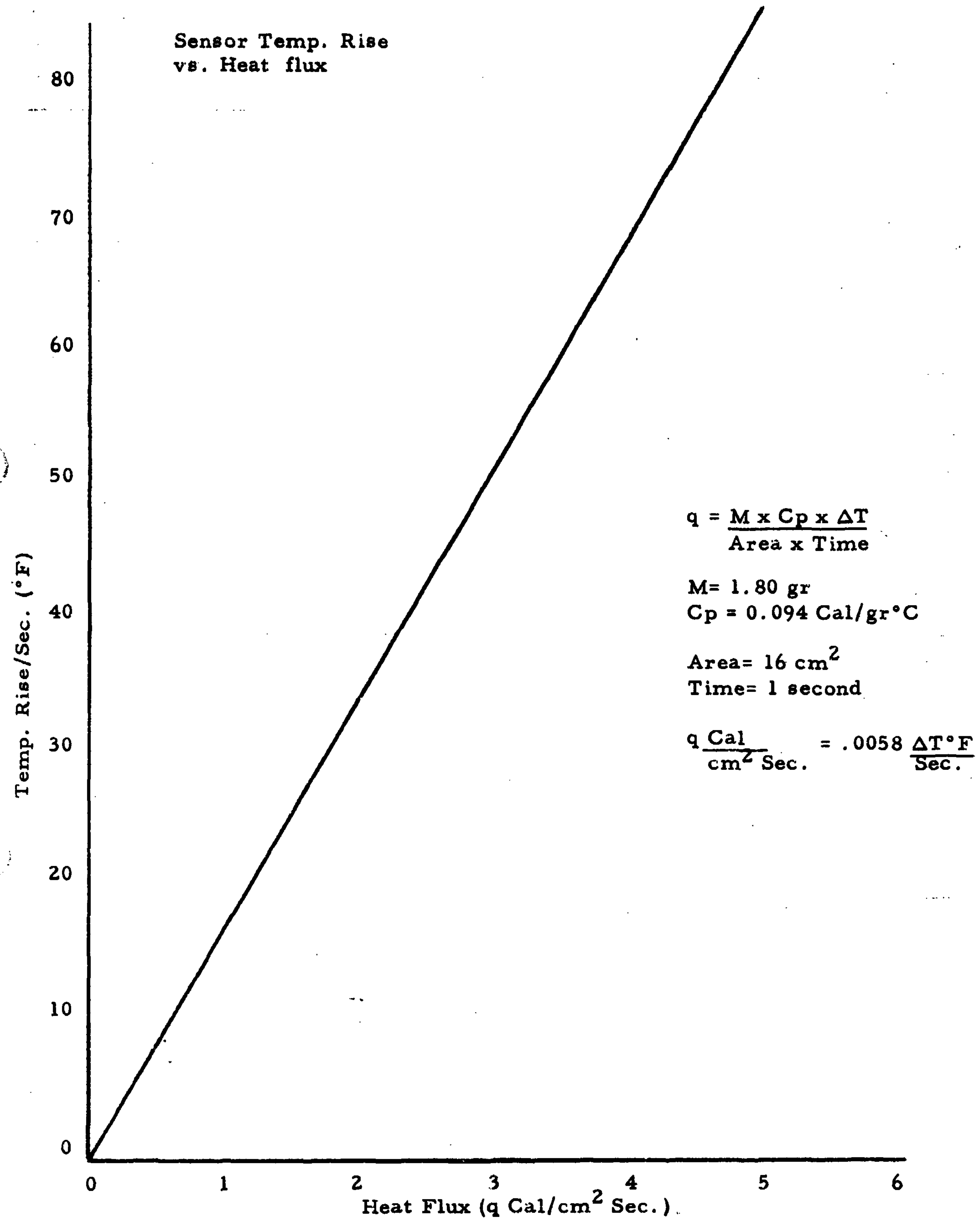
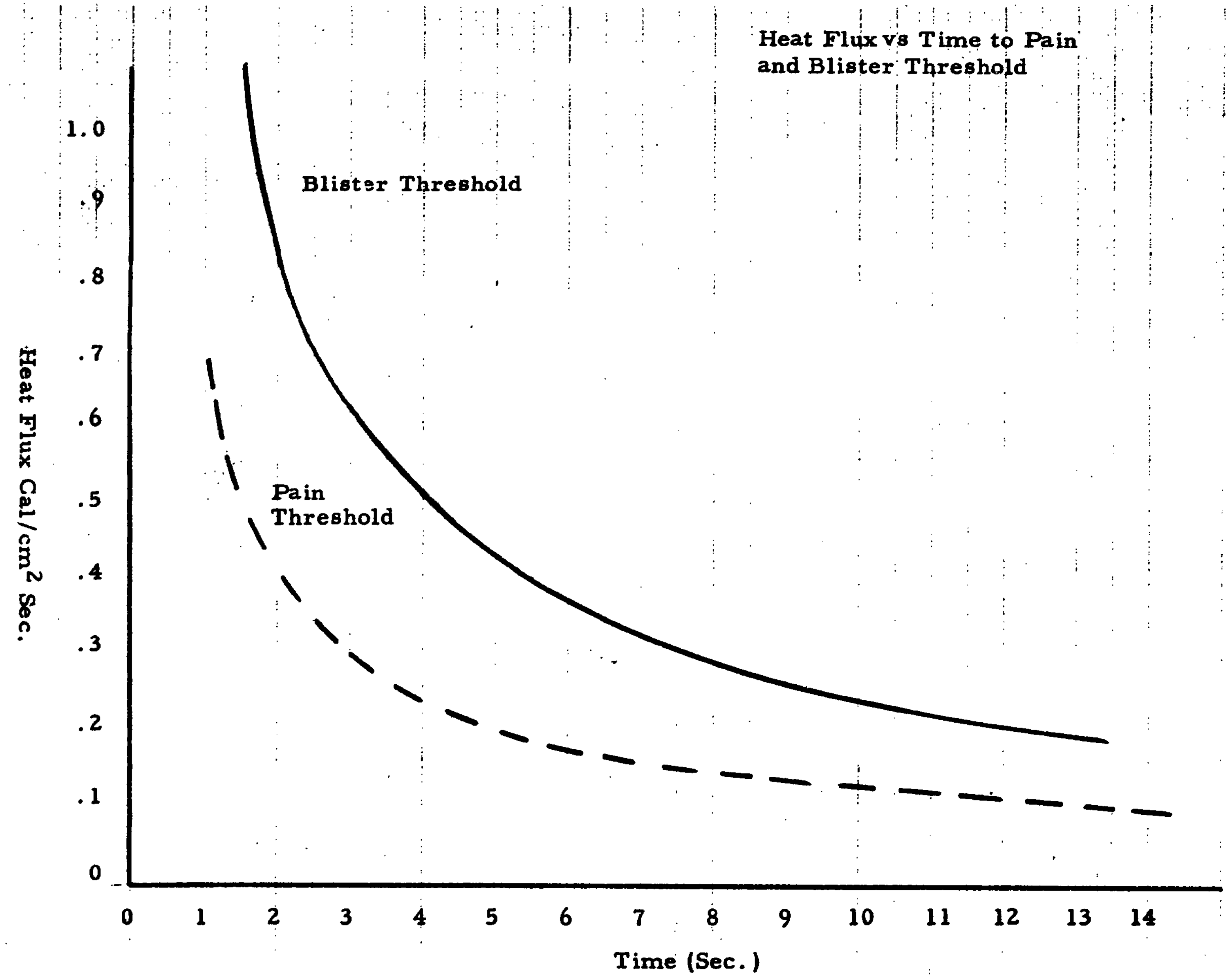
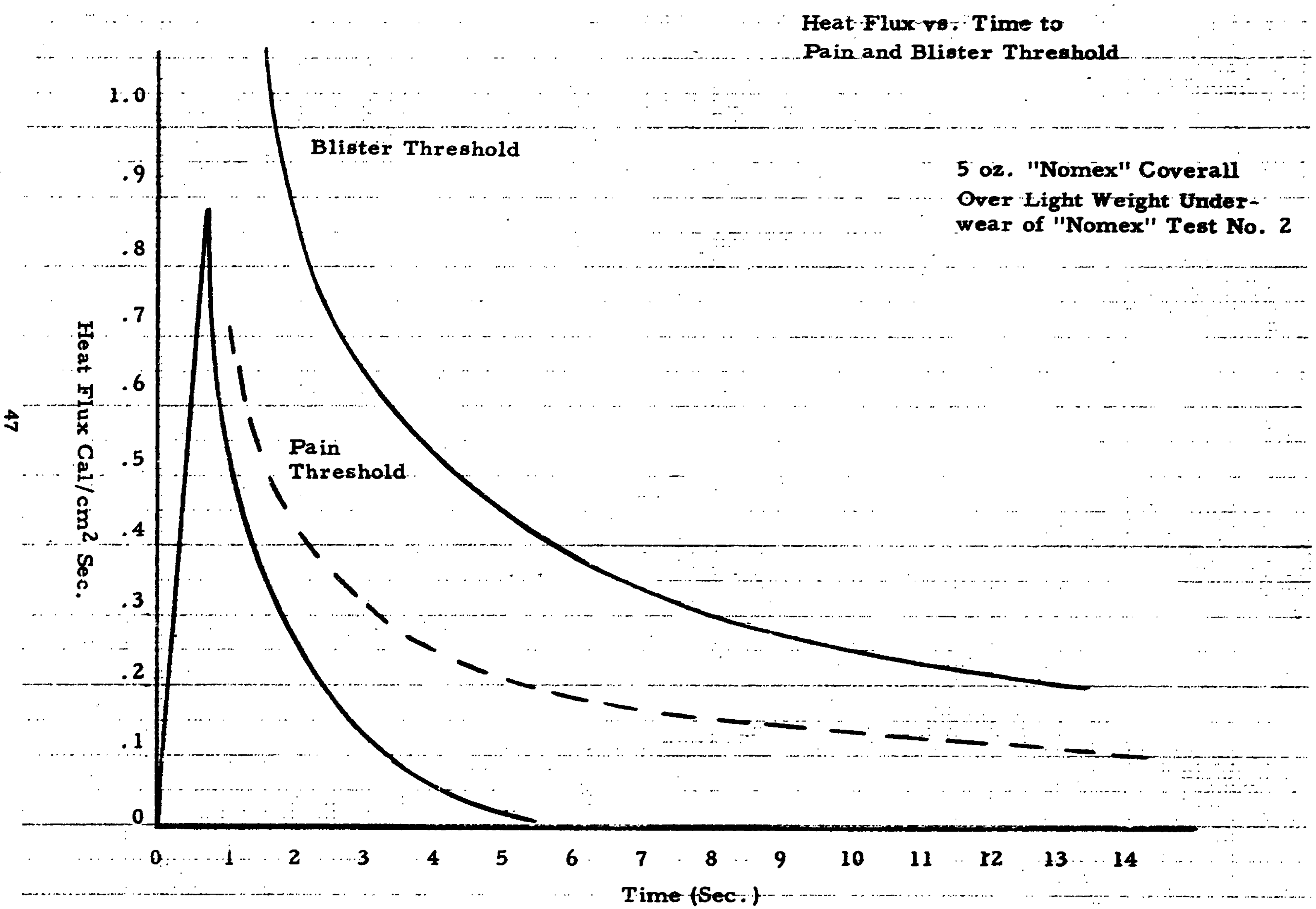

Sensor Temp. Rise
vs. Heat flux
80
70
60
50
40
30
20
10
0
Temp. Rise/Sec. (°F)
$q = \frac{M \times Cp \times \Delta T}{Area \times Time}$
M= 1.80 gr
Cp = 0.094 Cal/gr°C
Area= 16 cm^2
Time= 1 second
$q \frac{Cal}{cm^2\ Sec.} = .0058 \frac{\Delta T°F}{Sec.}$
0
1
2
3
4
5
6
Heat Flux (q Cal/cm^2 Sec.)

Figure 1



Heat Flux vs Time to Pain
and Blister Threshold
Blister Threshold
Pain
Threshold
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Time (Sec.)
Heat Flux Cal/cm2 Sec.

Figure 2



Heat Flux vs. Time to
Pain and Blister Threshold
5 oz. "Nomex" Coverall
Over Light Weight Under-
wear of "Nomex" Test No. 2
Blister Threshold
Pain
Threshold
Heat Flux Cal/cm2 Sec.
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Time (Sec.)

Figure 3

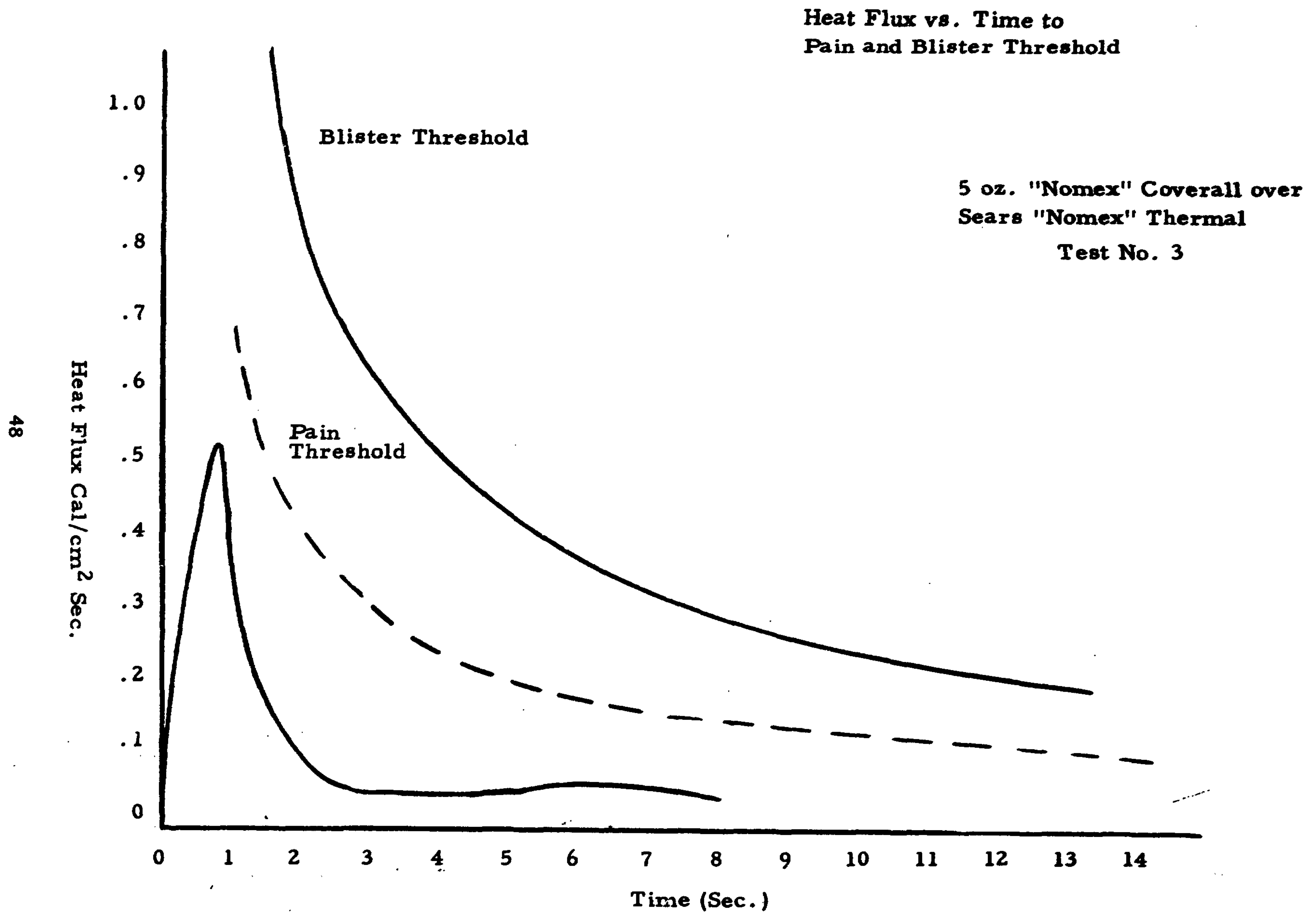

Heat Flux vs. Time to
Pain and Blister Threshold
5 oz. "Nomex" Coverall over
Sears "Nomex" Thermal
Test No. 3
Blister Threshold
Pain
Threshold
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
Heat Flux Cal/cm² Sec.
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Time (Sec.)

Figure 4

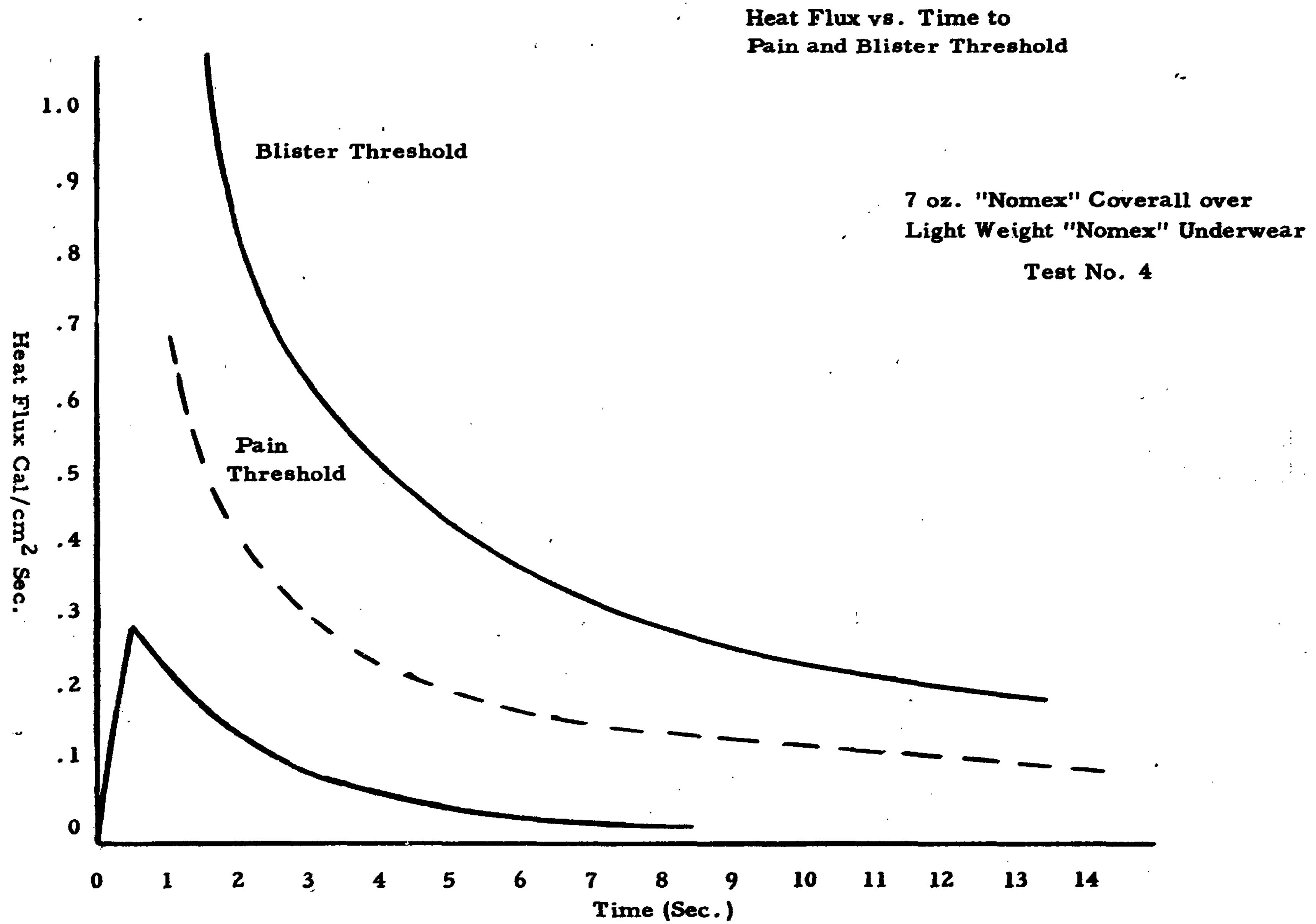
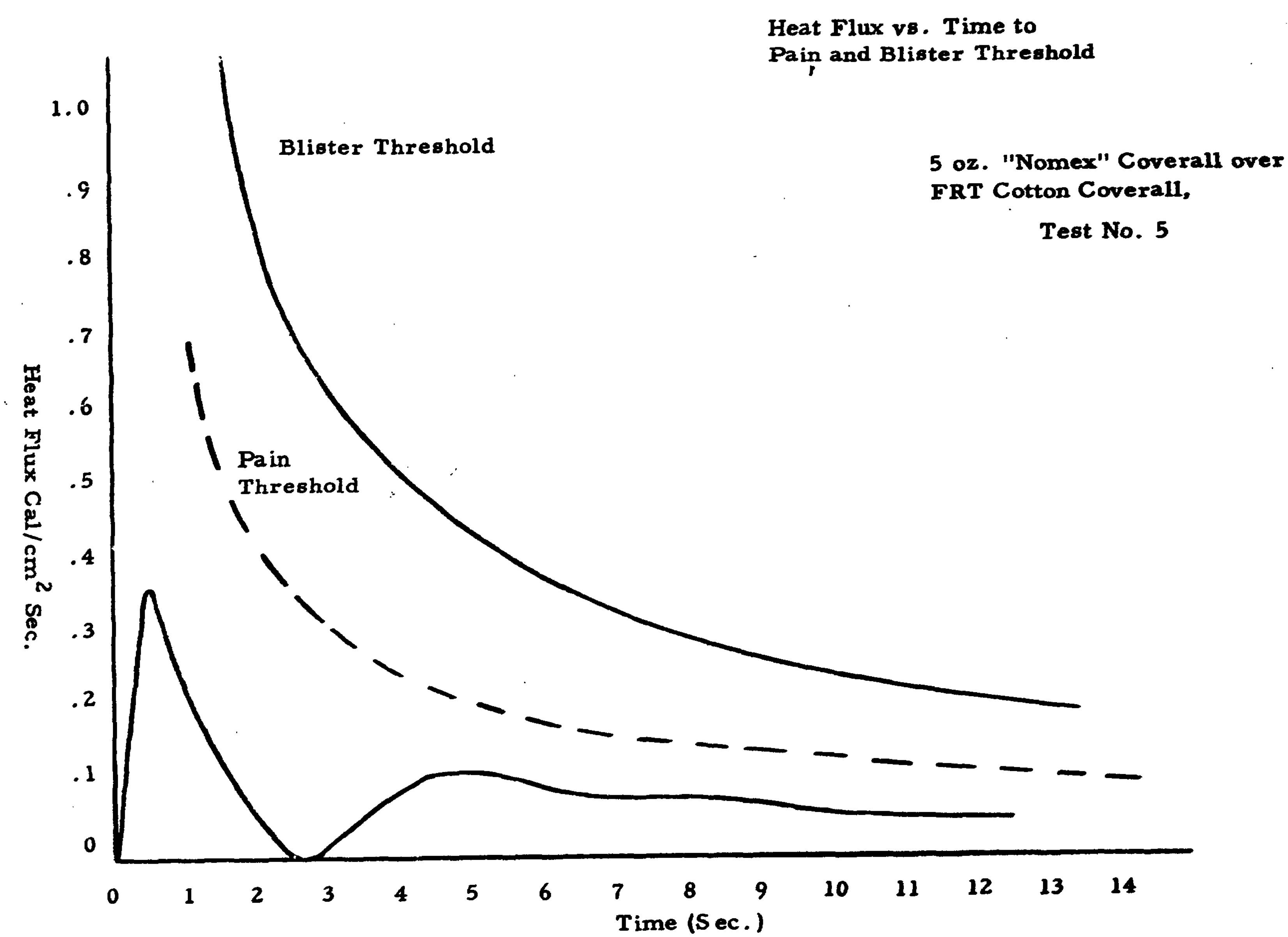

Heat Flux vs. Time to
Pain and Blister Threshold
7 oz. "Nomex" Coverall over
Light Weight "Nomex" Underwear
Test No. 4
Blister Threshold
Pain
Threshold
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
Heat Flux Cal/cm2 Sec.
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Time (Sec.)

Figure 5



Heat Flux vs. Time to
Pain and Blister Threshold
5 oz. "Nomex" Coverall over
FRT Cotton Coverall,
Test No. 5
Blister Threshold
Pain
Threshold
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
Heat Flux Cal/cm2 Sec.
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Time (Sec.)

Figure 6

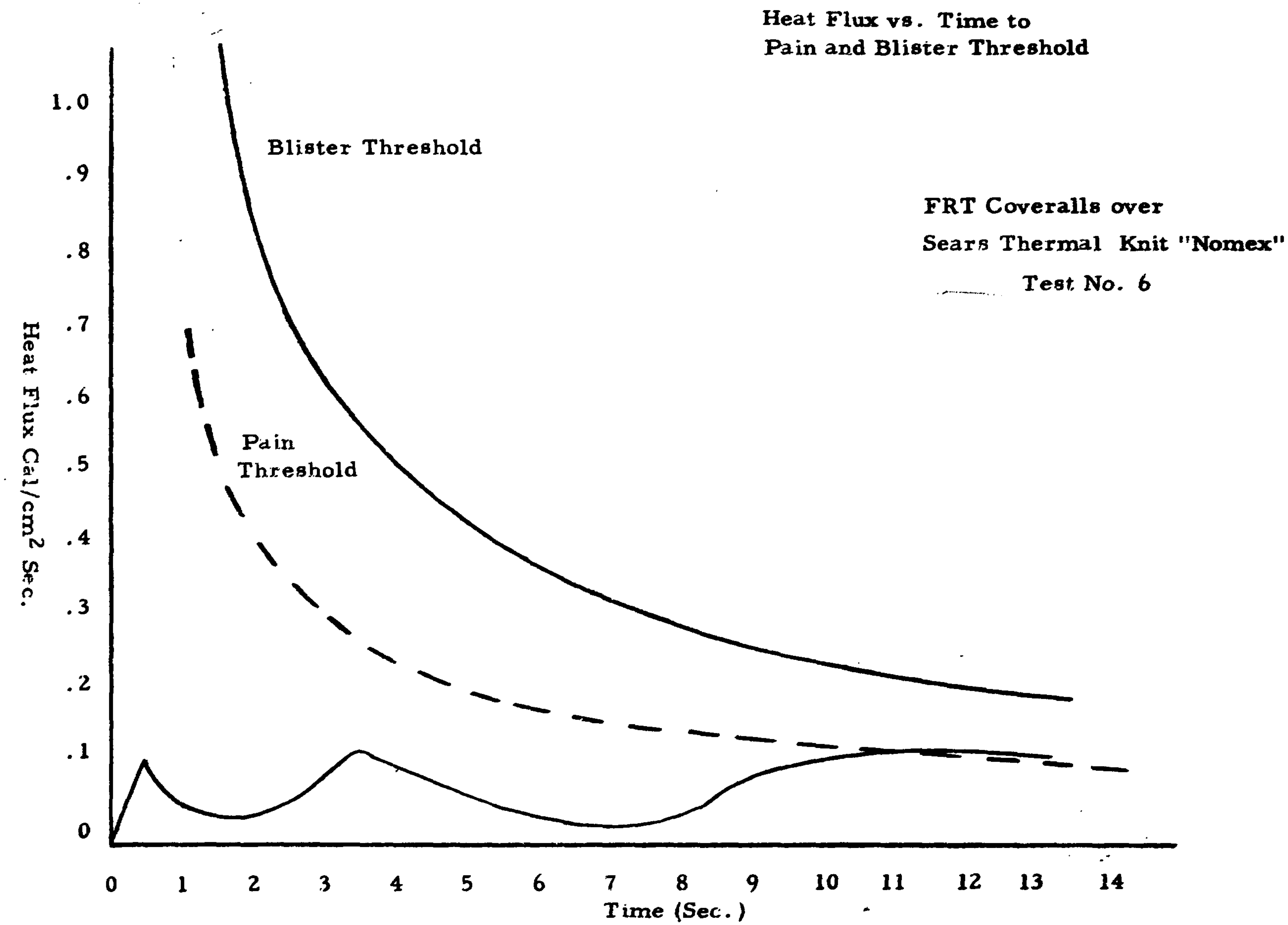

Heat Flux vs. Time to
Pain and Blister Threshold
FRT Coveralls over
Sears Thermal Knit "Nomex"
Test No. 6
Blister Threshold
Pain
Threshold
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
Heat Flux Cal/cm2 Sec.
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Time (Sec.)

Figure 7

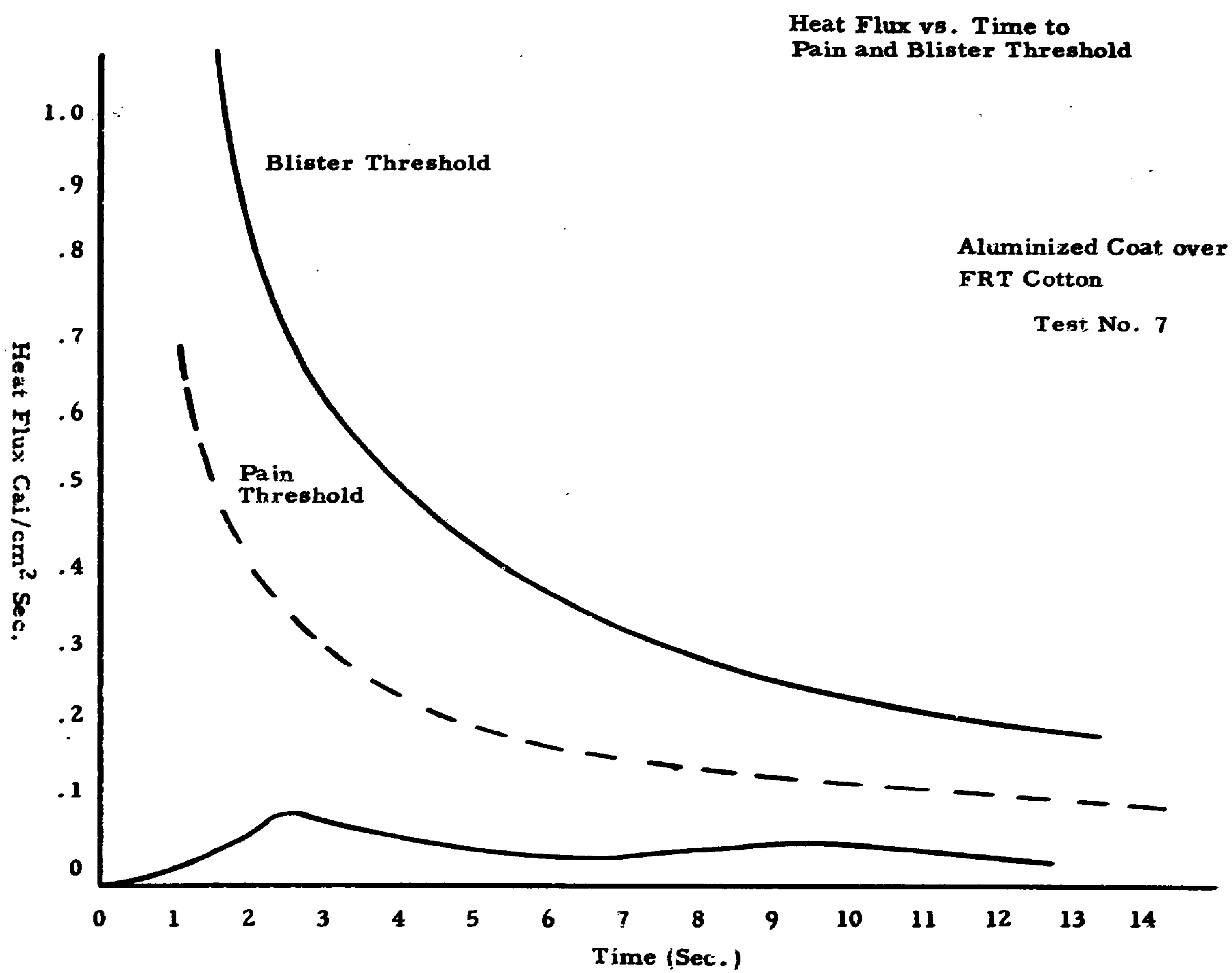

Heat Flux vs. Time to
Pain and Blister Threshold
Aluminized Coat over
FRT Cotton
Test No. 7
Blister Threshold
Pain
Threshold
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
Heat Flux Cal/cm² Sec.
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Time (Sec.)

Figure 8

Heat Flux vs. Time to
Pain and Blister Threshold

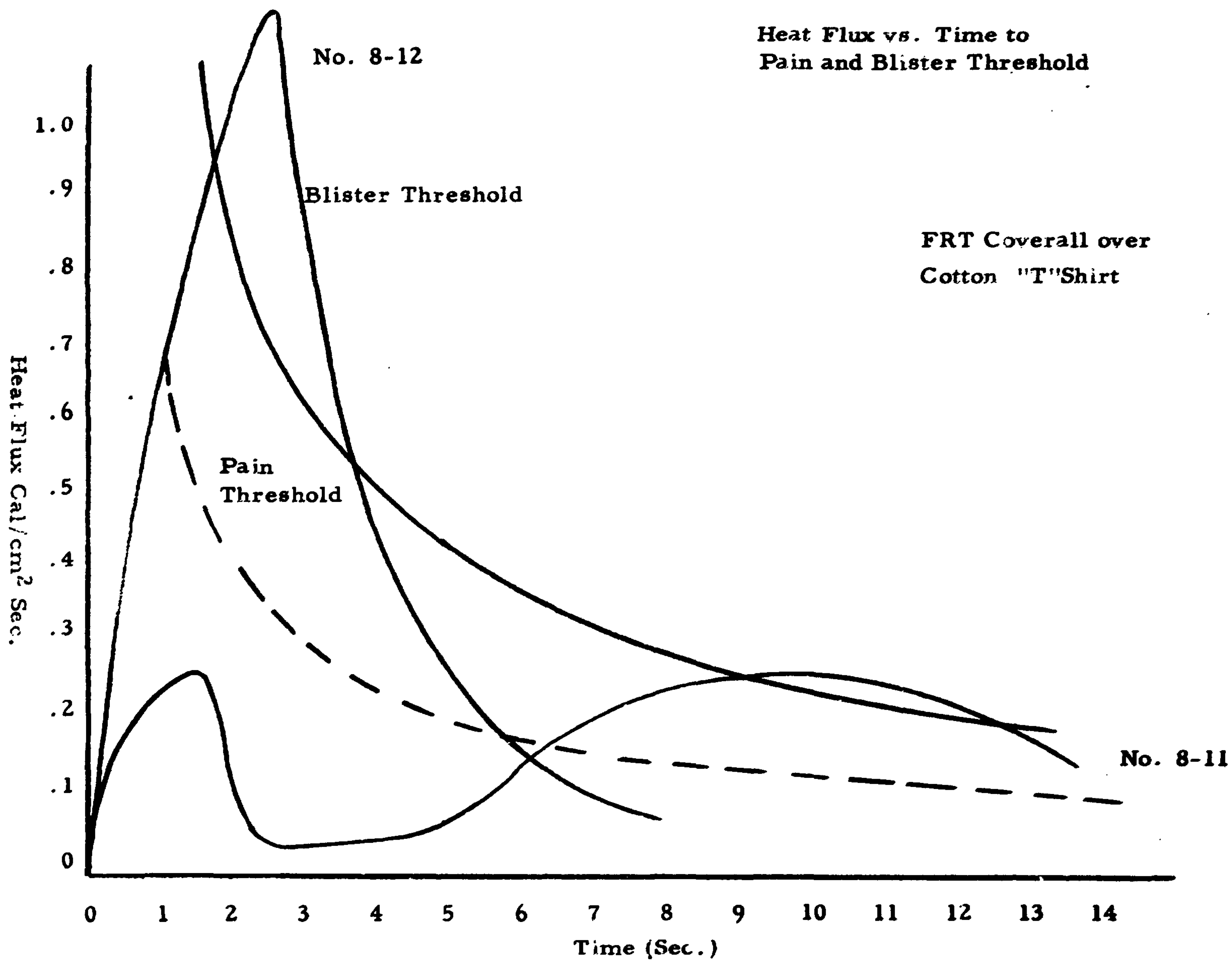


Figure 9)

Fig. 10
MANNEQUIN SHOWING THERMOCOUPLES IN POSITION

Fig. 11
TYPICAL TEST SET-UP (Test No. 2 - See Fig. 12 for Results)

Fig. 12
TEST RESULTS
TEST NO. 2
(Typical Results of 5-ounce "Nomex" Coveralls)

Fig. 13
TEST RESULTS
TEST NO. 4
(Typical Results of 7-ounce "Nomex" Coveralls)

Fig. 14
TYPICAL TEST SET-UP
(Test No. 6)

Fig. 15
RESULTS OF TEST
NO. 6

Fig. 16
TEST SET-UP
(Test No. 7)

Fig. 17
TEST RESULTS
(Test No. 7)

CONCLUSIONS

The heat flux versus time to pain and blister threshold curves (Figs. 3-9) indicate that clothing combinations worn in Tests 3, 4, and 7 should protect a person from burn when exposed to a source of heat similar to that used in the test. Clothing combinations worn in Tests 2, 6, and 8 would not be satisfactory in the presence of a high energy heat source since burns would likely occur. The clothing worn in Test 5 indicates protection in this test; however, there is a possibility that the flameproof cotton coveralls could burn more severely in additional testing. This combination (Test 5) would be considered a marginal system without additional testing to verify the results. (Note: Test 1 was conducted as a feasibility test only).

Although the aluminized fiberglass clothing has shown in this test series and in actual experience that it will protect the worker best, it has two distinct disadvantages. First, the coat is very uncomfortable to wear, especially in warm weather; second, it does not possess the resistance to chemicals that "Nomex" possesses. Table I, Appendix A, shows that after 1,000 hours of exposure to acetone, Freon 113, or alcohol, there was little or no effect on the breaking strength of the "Nomex" material.

The clothing combination worn in Test 4 appears to offer optimum protection for an industrial application such as Longhorn Army Ammunition Plant. This combination consists of the seven ounce "Nomex" coveralls and four and three-tenths ounce short sleeve and short leg underwear. This combination indicates a greater degree of protection than the five ounce "Nomex" coveralls over the seven ounce full length "Nomex" underwear as worn in Test 3, but did not protect as well as the bulky aluminized clothing as demonstrated in Test 7.

The ability of "Nomex" to protect is based to a large extent on the outer layer of material charring and trapping air between the outer and inner layers of cloth. (Fig. 13 - below the waist)

"Nomex" will be phased into use at Longhorn. Due to the problems associated with issueing two types of underclothing, it has been decided to use cotton underclothing with six ounce "Nomex" coveralls and six ounce "Nomex" laboratory type coats in the most hazardous locations. This combination, although not included in this series of tests, will provide protection equal to or better than the seven ounce coveralls over the four and three-tenths ounce underwear. With this combination, it will be easily ascertained that a person is properly clothed, and secondly, the laboratory coat will afford more coverage of the body than the short sleeve and short leg underwear.

APPENDIX A

"NOMEX" INFORMATION & DATA

CHEMICAL RESISTANCE OF "NOMEX"

INDUSTRIAL WEAR TEST

APPENDIX A

NOMEX INFORMATION AND DATA

Static Electricity

Many synthetic fabrics and some blends are subject to static electricity in low humidity atmospheres. There is no known permanent anti-static treatment; however, there are anti-static treatments which can be re-applied on washing and will control static electricity. To control static electricity, it is suggested that an antistat be applied in the final rinse water after the garments are washed. The following data indicates the degree of control possible with such an antistat:

	Electrical Resistivity in 10^8 OHMS at 25% R. H.
Fabrics of "Nomex", no anti-static treatment	93,000
100% cotton, no anti-static treatment	30,000
Fabrics of "Nomex" treated with an antistat	9,000

Some of the suitable antistats are:

"Ethoquad" 0/12
"Ethoquad" C/12
Armour Ind. Chemical Company
Chicago, Illinois

"Palostat"
DuPaul Chemical Company
Long Island, New York

"TLF" 1207
E. I. Du Pont de Nemours and Company
Wilmington, Delaware

Washing Procedure for Clothing of "Nomex"

Normal plant laundry procedures are satisfactory for "Nomex" with one exception: DO NOT ADD BLEACH! Normal detergents should be used as

long as they do not contain bleach.

A treatment for static should be added in the final rinse water. Antistat in the amount of 2% of the dry garment weight, be added for 40% relative humidity and above 4% for 20 to 40% relative humidity.

Availability

Although Du Pont is currently manufacturing "Nomex" fiber on a pilot line, they are producing a sufficient quantity to keep textile plants supplied. A production plant for manufacture of the "Nomex" fiber will be "on stream" this year. The only colors available are off-white and green. Other colors are currently being developed and will be available in 1968.

Cost

The initial cost of "Nomex" is quite high compared to cotton. Quotations received from various manufacturers bidding on the manufacture of 700 pair of six ounce men and women's coveralls ranged from $27 to $40. Although the initial cost is high in comparison to cotton, industrial wear tests show that there is an economic incentive to buy the "Nomex". (See Industrial Wear Tests, this appendix).

Since a powder suit is very simple to make, the cost, which is mostly the cost of the "Nomex" material, should drop once the "Nomex" fiber production plant is in operation.

TABLE I

CHEMICAL RESISTANCE OF "NOMEX" HIGH TEMPERATURE RESISTANT NYLON[1]

Chemical	Concentration (%)	Temperature (°F)	Temperature (°C)	Time (Hrs.)	Effect On Breaking Strength+: None	Slight	Moderate	Appreciable	Degraded
Strong, Mineral Acids									
Hydrochloric	10	203	95	8				X	
Hydrochloric	35	70	21	10	X				
Hydrochloric	35	70	21	100				X	
Nitric	10	70	21	100	X				
Nitric	70	70	21	100				X	
Sulfuric	10	70	21	100	X				
Sulfuric	10	140	60	1,000			X		
Sulfuric	60	140	60	100			X		
Sulfuric	70	70	21	100		X			
Sulfuric	70	203	95	8				X	
Organic Acids									
Acetic	100	70	21	1,000	X				
Acetic	100	200	93	10	X				
Benzenesulfonic	100	200	93	10				X	
Benzoic	sat. sol.	200	93	10	X				
Formic	91	70	21	1,000	X				
Formic	91	200	93	10		X			
Lactic	75	70	21	1,000	X				
Oxalic	10	200	93	10		X			
Oxalic	sat. sol.	70	21	1,000		X			
Trifluoroacetic	100	70	21	1,000		X			
Strong Alkalis									
Amm. hydroxide	28	70	21	100	X				
Sodium hydroxide	10	70	21	100	X				
Sodium hydroxide	10	140	60	100		X			
Sodium hydroxide	10	203	95	8				X	
Sodium hydroxide	40	70	21	10	X				
Sodium hydroxide	50	140	60	100					X
Bleaching Agents									
Peracetic acid	100	70	21	10	X				
Sodium chlorite	0.5	70	21	10	X				
Sodium chlorite	0.5	140	60	100			X		
Sodium hypochlorite	0.4	70	21	10	X				

[1] Extracted from "Properties of Nomex" Technical Information Bulletin N-201, Textile Fibers Department, Industrial Marketing Division, E. I. DuPont de Nemours & Co. Inc.

Chemical	Concentration/ Temperature (%)	(°F)	(°C)	Time (Hrs.)	Effect On Breaking Strength+ None	Slight	Moderate	Appreciable	Degraded
Organic Chemicals									
Acetone	100	70	21	1,000	X				
Acetone	100	133	**56	10	X				
Benzene	100	70	21	1,000	X				
Benzene	100	176	**80	10	X				
Carbon disulfide	100	70	21	1,000	X				
Carbon tetrachloride	100	70	21	1,000	X				
Carbon tetrachloride	100	171	**77	10	X				
Cresol (meta-)	100	70	21	1,000	X				
Cresol (meta-)	100	395	**202	10	X				
Dimethyl-acetamide	100	70	21	1,000		X			
acetamide	100	200	93	10	X				
formamide	100	158	70	168	X				
formamide	100	307	**153	10	X				
sulfoxide	100	70	21	1,000		X			
sulfoxide	100	200	93	10			X		
Ethyl alcohol	100	70	21	1,000	X				
Ethylene glycol	100	70	21	1,000	X				
Ethylene glycol	100	158	70	168	X				
Ethylene glycol	100	200	93	10	X				
Formaldehyde	10	70	21	1,000	X				
Freon-113*refrig.	100	70	21	1,000	X				
Gasoline (leaded)	100	70	21	1,000	X				
Jet fuel	100	158	70	168	X				
Methyl alcohol	100	70	21	1,000	X				
Methyl alcohol	100	148	**65	10	X				
Nitrobenzene	100	70	21	1,000	X				
Nitrobenzene	100	200	93	10	X				
Perchloroethylene	100	158	70	168	X				
Phenol	10	70	21	1,000	X				
Phenol	100	200	93	10	X				
Stoddard solvent	100	70	21	1,000	X				
Xylene (meta-)	100	158	70	168	X				
Sealed-Tube Exposures									
Air+5%water+5% sulfur dioxide++	--	347	175	100				X	
Freon-22* refrig.	--	356	180	1,000	X				
Sulfur hexafluoride	--	356	180	1,000		X			
Steam saturated at 79 psia.	--	311	155	100			X		

*Registered DuPont trademark
**boiling point
++Percent by weight

+None = 0-9% loss
Slight = 10-24% loss
Moderate = 25-44% loss
Appreciable = 45-79% loss
Degraded = 80-100% loss

INDUSTRIAL WEAR TEST

Chambers Works - E. I. DuPont de Nemours & Company

In June of 1963 a small wear test was initiated with the Engineering Maintenance Group at this Plant. Twenty-one garments were distributed to representative groups and the test was started.

After 13 months, the test was terminated despite the fact that only one set of garments had been worn out (a special case where "Nomex" outlasted FRT cotton 15-1). The Plant Clothing Committee had obtained sufficient information to demonstrate the advantage of "Nomex" over flame retardant treated cotton to the extent that they recommended the purchase of 500 sets of garments for a final prove-out.

In this preliminary test only a few garments had run long enough to justify cost, although at the termination all garments were in excellent shape. It did show that they were comfortable, easily cleaned, dimensionally stable and durable. On this basis a 500-garment test was initiated in November of 1965.

Garments for the final prove-out were distributed--two sets/operator--on the following basis:

Engineering	140
Manufacturing	140
Chemicals	140
Stores and Transport	80

These garments are now in their 18th month of use. Since each suit is worn every third day, this represents nearly six month's wear per garment. All garments are in excellent shape and an additional six month's wear per garment is expected. FRT cotton garments average 1-3 month's wear life with the average being 2 months. Thus far "Nomex" has a 3x wear life and is expected to reach at least 6x.

Niagara Falls - E. I. DuPont de Nemours & Company

Tests were initiated at this plant in September of 1965 and additional garments were supplied as indicated in following table. The table indicates the current status of the test. No garment failures have occurred and it is expected that they will reach 275 days (equivalent to one year's life).

Date Issued	Trousers or Overalls	Shirts	Days Worn Average/ Garment	Launderings Average/ Garment
9-13-65	4-T		226	45
9-27-65	1-T	1	236	47
12-15-65	13-T, 3-O	2	203	41
3-1-65	23-T, 10-O	19	171	34
	41-T, 13-O	22		

Records indicate that the cotton garments currently in use are replaced on the average every 15 wear days (based on average issue of 12 dungarees, 3 overalls and 11 shirts per employee per year).

On the basis of cost (cotton at $4/set vs. "Nomex" at $55/set), "Nomex" is already being justified on the basis of long life. It should also be noted that cotton garments are usually more expensive than $4/set, however, the severe environment has made it desirable to use less expensive garments.

APPENDIX B

"NOMEX" TEST SERIES

THERMOCOUPLES # 1 THROUGH 12

NOMEX TEST SERIES
DEGREES - F
THERMOCOUPLE NO. 1 - PALM OF RIGHT HAND

Time (Seconds)	1	2	3	4	5	6	7	8
	TEST NUMBER							
0.0	+79°	+62°	+75°	+71°	+59°	+58°	+60°	+70°
0.5	112	63	86	253	89	70	195	124
1.0	128	63	122	212	107	83	294	186
1.5	139	63	141	240	112	92	357	212
2.0	150	63	148	264	117	94	392	228
2.5	155	64	149	281	119	122	412	233
3.0	166	65	150	296	121	145	424	238
3.5		66	147	308	121	152	434	243
4.0		68	145	316	120	152	440	248
4.5		70	144	324	117	151	444	253
5.0		71	144	329		150	448	264
5.5		74	144	335		148	451	269
6.0		75	144	339			450	274
6.5		77	144	343			448	279
7.0		80	144	346			445	279
7.5		80	145	350				284
8.0		83	145	353				284
8.5		84	147	356				284
9.0		86	148	359				284
9.5		88	148	363				284
10.0		89	149	365				284
10.5		89	149	365				279
11.0		90	150	366				279
11.5		92	151	366				279
12.0		92	152	366				
12.5		92	152	365				
13.0		93	153	365				
13.5		94	154					
14.0		94	155					
Material Over Thermocouple	A	A	A	A	A	A	B	B

Legend:

A. Nomex Gloves Woven Over Knit

B. Edmont Standard

NOTE: Data reduction stopped once peak temperature was reached.

NOMEX TEST SERIES
DEGREES - F
THERMOCOUPLE NO. 2 - RIGHT WRIST

Time (Seconds)	TEST NUMBER 1	2	3	4	5	6	7	8
0.0	+62°	+57°	+71°	+79°	+43°	+56°	+60°	+60°
0.5	63	57	73	93	128	62	70	76
1.0	63	58	73	130	127	67	102	108
1.5	63	58	74	143	123	67	125	165
2.0	63	58	75	151	123	67	137	186
2.5	64	58	77	156	122	69	144	191
3.0	65	58	78	160	119	73	148	196
3.5	66	59	78	163	117	73	149	207
4.0	68	60	79	168		72	151	207
4.5	70	61	80	176		71	152	217
5.0	71	62	81	183			153	222
5.5	74	63	82	191			153	227
6.0	75	63	82	199			153	232
6.5	77	63	83	207			153	243
7.0	80	64	84	214			153	248
7.5	80	64	85	221			154	258
8.0	83	64	86	225			156	263
8.5	84	64	87	231			156	273
9.0	86	64	87	237			156	288
9.5	88	64	88	241			157	288
10.0	89	65	89	245			157	313
10.5	89	65	89	249			158	323
11.0	90	65	90	252			159	333
11.5	92	66	90	255			159	349
12.0	92	66	91	257			160	369
12.5	92	66	91	260			161	384
13.0	93	66	91	261			161	398
13.5	94	67	91	264			161	408
14.0	94	67	92	264			162	413
Material Over Thermocouple	A	B	B	B	B	B	C	D

Legend:

A. Leather Gauntlet of Nomex Glove
B. Nomex Gloves Woven Over Knit
C. Aluminized Coat Sleeve
D. Flameproof Cotton Coverall Sleeve

NOTE: Data reduction stopped once peak temperature was reached.

NOMEX TEST SERIES
DEGREES - F
THERMOCOUPLE NO. 3 - FRONT OF RIGHT BICEPT

Time (Seconds)	TEST NUMBER 1	2	3	4	5	6	7	8
0.0	+91°	+77°	+75°	+76°	+58°	+65°	+63°	+71°
0.5	114	92	83	95	63	72	63	77
1.0	124	116	92	145	70	83	63	87
1.5	131	129	94	155	81	84	64	129
2.0	138	133	95	163	91	85	64	145
2.5	142	136	97	170	98	89	63	160
3.0	147	141	97	175	103	96	63	181
3.5		150	98	178	107	110	63	211
4.0		158	98	184	110	120	63	237
4.5		166	98	191	110	127	63	262
5.0		172	99	197	112	132	63	277
5.5		176	99	203	113	137	63	282
6.0		177	99	209	113	140	63	297
6.5		178	99	214	113	147		312
7.0		179	99	217	113	152		327
7.5		177	99	222	113	155		342
8.0		176	99	224	113	157		352
8.5		175	99	226	113	158		367
9.0		173	99	227	114	163		377
9.5		170	100	229	114	164		391
10.0		168	100	233	115	165		401
10.5		166	100	235	116	165		411
11.0		164	100	237	117	165		431
11.5		162	100	238	118	166		441
12.0		160	100	241	119	166		461
12.5		158	100	242	120	166		476
13.0		155	100	243	121	167		490
13.5		153	100	244	122	169		510
14.0		151	100	244	122	170		525
Material Over Thermocouple	A	B	C	D	E	F	G	H

Legend:

A. 7 oz. Nomex Coveralls
B. 5 oz. Nomex Coveralls over 4.3 oz. Nomex Short Sleeve & Short Leg Underwear
C. 5 oz. Nomex Coveralls over 7 oz. Nomex Full Length Underwear
D. 7 oz. Nomex Coveralls over 4.3 oz. Nomex Short Sleeve & Short Leg Underwear
E. 5 oz. Nomex Coveralls over Flameproof Cotton Coveralls
F. Flameproof Cotton Coveralls over 7 oz. Nomex Full Length Underwear
G. Aluminized Coat over Flameproof Cotton Coveralls
H. Flameproof Cotton Coveralls over Cotton "T" Shirt

NOTE: Data reduction stopped once peak temperature was reached.

NOMEX TEST SERIES
DEGREES - F
THERMOCOUPLE NO. 4 - RIGHT CHEST

Time(Seconds)	TEST NUMBER 1	2	3	4	5	6	7	8
0.0	NO THERMOCOUPLE	+93°	+87°	+79°	+73°	+74°	+76°	+81°
0.5		104	102	93	79	80	76	86
1.0		157	138	130	90	81	76	91
1.5		165	153	143	109	81	80	108
2.0		176	159	151	125	82	89	124
2.5		187	163	156	136	83	102	134
3.0		194	169	160	142	83	113	140
3.5		198	177	163	145	84	121	150
4.0		201	184	168	146	84	127	150
4.5		203	190	176	148	85	133	155
5.0		205	195	183	150	65	137	155
5.5		205	200	191	153	85	141	160
6.0		205	024	199	158	86	144	160
6.5		205	208	207	164	86	148	166
7.0		205	210	214	171	87	152	166
7.5		202	213	221	177	88	156	171
8.0		202	215	225	184	89	161	171
8.5		201	217	231	191	90	165	176
9.0		199	219	237	197	90	170	181
9.5		197	220	241	204	91	174	186
10.0		195	221	245	210	91	178	192
10.5		193	222	249	215	92	181	192
11.0		191	224	252	221	92	185	197
11.5		188	224	255	226	93	187	197
12.0		185	225	257	233	94	191	202
12.5		183	225	260	238	94	193	202
13.0		180	225	261	243	95	195	207
13.5		178	226	264	248	96	196	207
14.0		175	225	264	252	96	198	207
Material Over Thermocouple		A	B	C	D	E	F	G

Legend:

A. 5 oz. Nomex Coveralls over 4.3 oz. Nomex Underwear
B. 5 oz. Nomex Coveralls over 7 oz. Nomex Underwear
C. 7 oz. Nomex Coveralls over 4.3 oz. Nomex Underwear
D. 5 oz. Nomex Coveralls over Flameproof Cotton Coveralls
E. Flameproof Cotton Coveralls over 7 oz. Nomex Underwear
F. Aluminized Coat over Flameproof Cotton Coveralls
G. Flameproof Cotton Coveralls over Cotton "T" Shirt

D

NOMEX TEST SERIES
DEGREES - F
THERMOCOUPLE NO. 5 - RIGHT SIDE

Time (Seconds)	TEST NUMBER 1	2	3	4	5	6	7	8
0.0	NO THERMOCOUPLE	+68°	+75°	+76°	+56°	+63°	+68°	+72°
0.5		79	84	87	61	70	68	83
1.0		93	100	96	67	78	68	83
1.5		98	116	99	68	79	68	88
2.0		100	125	102	69	79	68	98
2.5		101	127	104	71	79	68	98
3.0		103	127	105	71	79	68	104
3.5		104	127	108	72	80	68	109
4.0		105	127	110	73	80	68	114
4.5		106	125	111	73	80	68	119
5.0		106	125	112	75	81	68	119
5.5		106	124	112	76	81	68	119
6.0		106	124	113	76	81	68	124
6.5		106	123	114	78	82	68	129
7.0		106	123	114	78	83	68	135
7.5		106	124	114	78	84	68	140
8.0		106	126	113	79	85	68	145
8.5		106	128		80	85	68	150
9.0		106	130		81	87	68	155
9.5		105	131		81	88	69	160
10.0		105	132		81	90	69	170
10.5		105	132		82	91	69	180
11.0		105	132		82	93	70	195
11.5		104	133		83	95	70	201
12.0		103	133		84	97	70	206
12.5		103	133		84	98	70	216
13.0		103	133		85	101	70	221
13.5		103	134		85	102	71	226
14.0		103	133		85	105	71	231
Material Over Thermocouple		A	B	C	D	E	F	G

Legend:

A. 5 oz. Nomex Coveralls over 4.3 oz. Nomex Underwear
B. 5 oz. Nomex Coveralls over 7 oz. Nomex Coveralls
C. 7 oz. Nomex Coveralls over 4.3 oz. Nomex Underwear
D. 5 oz. Nomex Coveralls over Flameproof Cotton Coveralls
E. Flameproof Cotton Coveralls over 7 oz. Nomex Underwear
F. Aluminized Coat over Flameproof Cotton Coveralls
G. Flameproof Cotton Coveralls over Cotton "T" Shirt.

NOTE: Data reduction stopped once peak temperature was reached.

NOMEX TEST SERIES
DEGREES - F
THERMOCOUPLE NO. 6 - RIGHT THIGH

Time (Seconds)	TEST NUMBER 1	2	3	4	5	6	7	8
0.0	[illegible]1°	+64°	+79°	+75°	+67°	+67°	+86°	+78°
0.5	110	64	86	79	67	71	86	78
1.0	250	75	120	116	75	101	86	133
1.5	368	79	143	143	101	139	90	188
2.0	429	79	150	150	124	161	94	221
2.5	435	79	154	157	135	172	98	258
3.0	437	79	154	157	135	176	105	301
3.5		79	154	168	139	183	109	370
4.0		83	154	183	139	190	116	475
4.5		83	154	197	139	201	120	534
5.0		83	157	208	143	209	124	634
5.5		83	161	223	146	220	128	719
6.0		83	161	230	154	227	131	810
6.5		83	161	245	157	238	135	853
7.0		87	161	248	161	245	139	858
7.5		87	161	259	165	256	143	921
8.0		87	165	263	168	263	150	937
8.5		87	165	266	168	270	154	942
9.0		87	165	273	176	278	157	916
9.5		87	165	277	179	288	161	889
10.0		87	165	281	183	296	165	863
10.5		87	165	284	187	299	168	826
11.0		87	165	288	187	303	172	
11.5		90	165	288	190	306	172	
12.0		90	165	288	194	310	176	
12.5		90	165	288	198	310	179	
13.0		90	165	291	198	310	183	
13.5		90	165	291	198	310	183	
14.0		90	161	295	201	310	183	
Material Over Thermocouple	A	B	C	D	E	F	G	H

Legend:

A. 7 oz. Nomex Coveralls
B. 5 oz. Nomex Coveralls over 4.3 oz. Nomex Underwear
C. 5 oz. Nomex Coveralls over 7 ox. Nomex Underwear
D. 7 oz. Nomex Coveralls over 4.3 oz. Nomex Underwear
E. 5 oz. Nomex Coveralls over Flameproof Cotton Coveralls
F. Flameproof Cotton Coveralls over 7 oz. Nomex Underwear
G. Aluminized Coat over Flameproof Cotton Coveralls
H. Flameproof Cotton Coveralls

NOTE: Data reduction stopped once peak temperature was reached.

NOMEX TEST SERIES
DEGREES - F
THERMOCOUPLE NO. 7 - RIGHT SIDE OF NECK

Time (Seconds)	1	2	3	4	5	6	7	8
				TEST NUMBER				
0.0		+54°	+73°	+69°	+44°	+46°	+66°	+66°
0.5		72	80	93	78	73	101	114
1.0		271	129	159	149	95	167	170
1.5		291	141	187	150	97	344	196
2.0		290	145	195	151	95	398	186
2.5		283	144	198	151	95	392	186
3.0		276	143	198	152	95	377	186
3.5		266	141	200	153	95	356	186
4.0		256	140	202	149	93		176
4.5		249	140	204	145			170
5.0		244		203				165
5.5		235		202				
6.0		227						
6.5		219						
7.0		210						
7.5		202						
8.0		194						
8.5		187						
9.0		179						
9.5		174						
10.0		171						
10.5		166						
11.0		160						
11.5		154						
12.0		149						
12.5		145						
13.0		140						
13.5		137						
14.0		134						

FACE SHIELD COVERING THERMOCOUPLE
DURING EACH TEST

NOTE: Data reduction stopped once peak temperature was reached.

NOMEX TEST SERIES
DEGREES - F
THERMOCOUPLE NO. 8 - RIGHT CHEST BETWEEN INNER AND OUTER GARMENT

Time (Seconds	TEST NUMBER 1	2	3	4	5	6	7	8
0.0	+105°	+79°	+76°	+72°	+64°	+63°	+74°	+66°
0.5	148	84	113	125	143	80	79	77
1.0	249	108	222	183	377	93	144	82
1.5	307	111	287	222		98	231	88
2.0	335	113	326	273		99	307	88
2.5	344	117	351	299		103	351	93
3.0	344	118	362	316		114	379	98
3.5		118	365	331		122	397	109
4.0		119	366	342		124	409	119
4.5		119	362	356		126	418	124
5.0		120	359	368		148	425	124
5.5		121	358	378		193	429	124
6.0		121		386		248	432	129
6.5		122		393		311	435	134
7.0		124		399		364	435	134
7.5		124		403		394	436	134
8.0		125		405		419	436	134
8.5		126		406		451	435	134
9.0		127		406		473	434	140
9.5		128		403		496	432	140
10.0		129		397		522		145
10.5		129				560		145
11.0		131						145
11.5		131						145
12.0		132						150
12.5		132						155
13.0		133						155
13.5		134						160
14.0		134						160
Material Over Thermocouple	A	B	B	A	B	C	D	C

Legend:

A. 7 oz. Nomex Coveralls
B. 5 oz. Nomex Coveralls
C. Flameproof Cotton Coveralls
D. Aluminized Coat

NOTE: Data reduction stopped once peak temperature was reached.

NOMEX TEST SERIES
DEGREES - F
THERMOCOUPLE NO. 9 - RIGHT CHEST - OUTSIDE

Time (Seconds)	TEST NUMBER							
	1	2	3	4	5	6	7	8
0.0	+80°	+75°	+68°	+68°	+47°	+55°	+81°	+76°
0.5	769	294	315	333	1815	121	535	313
1.0	1209	1174	1111	773	----	171	1165	484
1.5	1292	1183	1137	805	1660	171	1469	513
2.0	1301	1147	1067	858	1542	164	1502	529
2.5	1264	1084	991	844	1402	157	1438	544
3.0	1200	1009	921	854		146	1362	559
3.5		925	862	851		139	1273	589
4.0		862		844		132		609
4.5		808		826				629
5.0		751		787				644
5.5		709						659
6.0		677						675
6.5		648						690
7.0		624						705
7.5		585						715
8.0		563						715
8.5		549						725
9.0		531						740
9.5		513						745
10.0		496						765
10.5		478						776
11.0		460						786
11.5		439						791
12.0		429						811
12.5		411						826
13.0		393						836
13.5		380						861
14.0		365						866

NOTE: Data reduction stopped once peak temperature was reached.

NOMEX TEST SERIES
DEGREES - F
THERMOCOUPLE NO. 10 - RIGHT TEMPLE

Time (Seconds)	TEST NUMBER 1	2	3	4	5	6	7	8
0.0	+72°	+55°	+73°	+64°	+54°	+64°	+67°	+61°
0.5	72	55	73	65	57	66	68	72
1.0	73	91	76	72	74	73	76	93
1.5	73	95	81	78	80	74	113	103
2.0	75	89	81	80	90	75	115	103
2.5	75	84	81	80	93	75	108	103
3.0	75	81	81	78	95	74	103	103
3.5		78	81	77	96	74	100	103
4.0		76	81	77	97	73		103
4.5		76	81	77	97			103
5.0		74	81	78	96			98
5.5		72	81		95			93
6.0		71	81		95			93
6.5		70	81		94			93
7.0		70	81					93
7.5		68	80					88
8.0		67	80					88
8.5		67						88
9.0		66						
9.5		65						
10.0		65						
10.5		65						
11.0		65						
11.5		64						
12.0		63						
12.5		63						
13.0		63						
13.5		63						
14.0		62						

FACE SHIELD COVERING THERMOCOUPLE DURING EACH TEST

NOTE: Data reduction stopped once peak temperature was reached.

NOMEX TEST SERIES
DEGREES - F
THERMOCOUPLE NO. 11 - RIGHT CHEST

Time (Seconds)	1	2	3	4	5	6	7	8
					TEST NUMBER			
0.0	NO THERMOCOUPLE	+87°	+87°	+82°	+74°	+76°	+79°	+71°
0.5		113	109	107	85	86	79	93
1.0		190	154	134	139	97	79	103
1.5		230	179	147	159	100	79	134
2.0		250	181	137	163	104	81	150
2.5		266	185	163	164	107	81	170
3.0		278	190	165	164	114	83	176
3.5		285	195	173	166	126	86	191
4.0		290	201	181	174	136	88	201
4.5		294	205	189	185	145	91	261
5.0		295	210	194	195	152	95	227
5.5		296	215	199	204	158	100	237
6.0		297	220	204	213	163	104	257
6.5		296	225	207	221	169	107	272
7.0		295	230	211	229	170	107	297
7.5		293	233	215	237	172	112	317
8.0		291	237	217	244	172	114	337
8.5		289	241	220	251	175	116	357
9.0		287	245	222	257	177	117	382
9.5		283	248	224	263	180	121	401
10.0		280	252	227	268	189	123	421
10.5		276	255	228	274	199	124	446
11.0		273	258	229	278	209	126	465
11.5		269	261	229	282	222	128	485
12.0		264	261	230	286	231	129	510
12.5		260	264	230	289	241	131	525
13.0		255	264	230	293	251	133	545
13.5		251	265	230	297	262	133	565
14.0		245	265	230	301	272	135	575
Material Over Thermocouple		A	B	C	D	E	F	G

Legend:

A. 5 oz. Nomex Coveralls over 4.3 oz. Nomex Underwear
B. 5 oz. Nomex Coveralls over 7 oz. Nomex Underwear
C. 7 oz. Nomex Coveralls over 4.3 oz. Nomex Underwear
D. 5 oz. Nomex Coveralls over Flameproof Cotton Coveralls
E. Flameproof Cotton Coveralls over 7 oz. Nomex Underwear
F. Aluminized Coat over Flameproof Cotton Coveralls
G. Flameproof Cotton Coveralls over Cotton "T" Shirt

NOMEX TEST SERIES
DEGREES - F
THERMOCOUPLE NO. 12 - RIGHT THIGH

TEST NUMBER

Time (Seconds)	1	2	3	4	5	6	7	8
0.0	NO THERMOCOUPLE	+81°	+89°	+85°	+75°	+70°	+89°	+81°
0.5		93	96	93	79	74	89	91
1.0		161	151	137	98	98	90	176
1.5		206	163	147	117	102	92	233
2.0		223	167	153	129	103	98	320
2.5		239	169	158	137	109	107	426
3.0		249	170	161	142	113	116	522
3.5		256	171	165	145	120	124	614
4.0		261	172	167	148	125	131	649
4.5		264	174	171	150	131	139	675
5.0		266	176	173	153	137	144	690
5.5		268	178	176	157	142	150	700
6.0		270	179	178	161	146	154	705
6.5		270	180	181	165	149	158	715
7.0		270	182	184	170	153	161	741
7.5		270	182	186	174	157	166	746
8.0		270	183	188	179	160	169	751
8.5		273	184	190	183	162	173	751
9.0		279	185	193	188	164	176	746
9.5		285	185	195	190	165	181	741
10.0		291	186	197	193	165	186	741
10.5		294	186	199	197	165	191	730
11.0		294	186	201	199	165	194	720
11.5		291	186	201	201	165	197	705
12.0		288	185	203	202	163	201	695
12.5		284	185	204	204	162	205	685
13.0		279	184	204	205	161	207	664
13.5		275	184	206	207	160	210	659
14.0		270	183	208	207	159	212	639
Material Over Thermocouple		A	B	C	D	E	F	G

Legend:
- A. 5 oz. Nomex Coveralls over 4.3 oz. Nomex Underwear
- B. 5 oz. Nomex Coveralls over 7 oz. Nomex Underwear
- C. 7 oz. Nomex Coveralls over 4.3 oz. Nomex Underwear
- D. 5 oz. Nomex Coveralls over Flameproof Cotton Coveralls
- E. Flameproof Cotton Coveralls over 7 oz. Nomex Underwear
- F. Aluminized Coat over Flameproof Cotton Coveralls
- G. Flameproof Cotton Coveralls

H. J. STONE, LOCKHEED MISSILES & SPACE CO. What were the temperature readings in the palm of the hand? I was wondering if you had the Nomex protection in the glove or if the glove was made of the Nomex?

ATTAWAY: The highest temperature recorded on the palm of the hand in any test was 365°. On the first test it was 166°, the second 94°, the third 155°, the fourth 365°, fifth 117°, sixth 148°, etc.

STONE: Was it a regular glove then?

ATTAWAY: It was an aluminized glove.

C. I. VOGT, NOS INDIAN HEAD, MD: Did you say the material was nylon?

ATTAWAY: Nomex.

VOGT: Is it a nylon material?

ATTAWAY: Right.

VOGT: I'm concerned with nylon itself or nylon on nylon as static generators. How are you accounting for this?

ATTAWAY: You're quite right and the material can be protected against static generation. The du Pont people have materials that will take care of the static generation qualities of it. The fabric itself with no anti-static treatment has an electrical resistivity of 9,000 ohms. But you can buy Pelostat or TLF or Ethoquad from various companies and treat them with that to keep it static free.

DAMAGE CONTROL & EXTINGUISHMENT TECHNIQUES
FOR MAGNESIUM FLARE COMPOSITIONS

by

W. E. Carper, NAD Crane, Indiana

Introduction

Several incidents of accidental ignition of the Mk 24 Aircraft Parachute Flare have made it necessary to find a method to extinguish this flare. Earlier assumptions that this magnesium flare with its own oxidizer could not be extinguished had been discounted by the U. S. Air Force. The Air Force had been successful in extinguishing the flare with water.

Tests were designed to determine the most effective approach to fighting a flare fire. These tests included various fire fighting agents, several methods of attacking the fire and variety of equipments capable of extinguishing the fire.

The majority of the testing was concerned with single flares in open space as might be experienced on an airfield or a flight deck of an aircraft carrier. Limited testing was conducted on multiple flare fires in open space but no testing was done in confined areas such as magazines or ready service lockers.

Pretest Analysis

I. Composition of Mk 24 A.P. Flare: Magnesium (balls or flakes of granular size), oxidizer (granular sodium nitrate) and styrene monomer binder.

II. Rate of Heat Output (QA):

H = Approximately 3600 cal/gram (6,475 btu/lb)

T = Flare burns for a total of 180 secs.

W = Composition in flare candle weighs 15 lb.

$$QH = \frac{H \times W}{T} = \frac{6475 \frac{\text{btu}}{\text{lb}} \times 15 \text{ lb}}{180 \text{ sec}}$$

Q_H = 540 btu/sec

III. Temperature in Fireball: Approximately 4500°F

IV. The maximum temperature at 6, 8, 10 and 12 feet from the flare and in line with the burning end of the flare was determined. (See Figure 1). The tests indicated that a fire fighter could safely approach the flare from the front at a distance of 15 feet. During actual extinguishing tests, it was shown that the fire fighter could stand adjacent to the side of the flare. Also, it was found that the use of water fog served as an effective heat shield for close range frontal approach.

Reignition temperatures were also investigated. A heating coil was placed against the face of a partially burnt candle. A thermocouple was then placed in the center of the heating coil and against the flare face. Heat was gradually applied until reignition occurred. (See Figure 2).

V. Problem Statement: To find an effective extinguishing agent and mode of application for extinguishing Mk 24 A. P. Flares.

A. Selection of extinguishing agent:

1. The flare composition contains an oxidizer; thus, extinguishing agents which function primarily via oxygen (air) exclusion would not be effective. An extinguishing agent that functions via cooling would then be the logical choice.

2. Water provides the best heat absorbing characteristics per pound (1123 btu/lb at 70°F) and is readily available for use.

B. Rate of water application required:

1. Heat output rate, Q_H = 540 btu/sec

2. Heat absorbation water, Q_W = 1123 btu/lb

3. Weight water per gallon = $\frac{8.34\ \text{lb}}{\text{gal}}$

Water flow in gallons per second required to cool flare =

$$\text{G.P.S.} = \frac{Q_H}{Q_W \times \frac{8.34\ \text{lb}}{\text{gal}}}$$

$$= \frac{540\ \frac{\text{btu}}{\text{sec}}}{1123\ \frac{\text{btu}}{\text{lb}} \times \frac{8.34\ \text{lb}}{\text{gal}}}$$

= 0.06 gallons per second

C. Standard delivery rates for fire fighting devices:

1 1/2" fog applicator, 100	1.7 gps
1 1/2" all-purpose nozzle, 100 psi, 180° fog . . .	2.5 gps
1 1/2" all-purpose nozzle, 100 psi, solid stream .	9.3 gps
1 1/2" all-purpose nozzle, 25 psi, solid stream. .	7.5 gps
2 1/2 gallon, press. water fire ext.	Average 07 for first 25 secs.

D. Method of water application: Since the primary extinguishing effect desired is cooling, the finely divided water particles produced by an all-purpose nozzle in a 180° fog position or a fog applicator would perform best.

E. Hydrogen Generation:

1. The magnesium in the Mk 24 AP Flare is pre-coated with a plastic binder. The only exposed magnesium during burning of the flare would be at the flame front. The total surface area is approximately 18 square inches of which 50% is magnesium in a homogeneous mixture. Thus, any hydrogen produced will be negligible and will be consumed as rapidly as it is generated.

2. The Mk 24 AP Flare does not produce enough heat to thermally dissociate water into hydrogen and oxygen.

Tests: Extinguishment Mk 24 A.P. Flare

Test No. 1:

Steel plates, 1/2" thick, were placed on the ground to simulate a ship deck. A shield was installed to protect the fire fighter (Note: Since exact reaction of the magnesium flare could not at this point be predicted, the shield was used for the fire extinguisher tests. The fire hose was used in the open). Candles were placed on the steel plate directly in line with the opening cut in the shield for operating the fire extinguishers. The candles were ignited with a squib and the ignition discs used in the Mk 24 A.P. Flare. All of the candles were allowed to burn for 30 seconds before extinguishment was attempted.

Extinguishment was attempted using:

1. 2 1/2 gallon, stored water pressure units at 100 and 175 psi. Part of the units contained fresh water, part a water and antifreeze mix.

2. 2 1/2 gallon, hand pump unit containing salt water.

3. 15 lb carbon dioxide unit with the diffuser removed to increase stream pressure and flow rate.

4. 30 lb Met-L-X unit with a 1/4 inch straight nozzle for increased stream pressure and flow rate.

5. 1 1/2 inch all-purpose nozzle on solid stream at 20 psi nozzle pressure.

6. 4 gallons of water in a bucket. Water tossed directly at face of burning candle.

Test No. 2:

Candles were suspended over a 12 gallon, GI can and a 55 gallon drum filled with water. After a 30 second burning time, the candles were dropped into the GI can and the 55 gallon drum. The candles were dropped with the burning end up and the burning end down. During some of the tests, an all-purpose nozzle on a 2 1/2 inch line was used to add water to the drum after the flare had dropped.

Test No. 3:

Candles were placed on the steel plate as in Test No. 1, but the operator's shield was not used. Flares were extinguished with:

1. 2 1/2 gallon water pressure units.

2. All-purpose nozzle on solid stream at 20 psi nozzle pressure.

3. 6 foot fog applicator with pump pressures of 70, [illegible] and 125 psi.

Test No. 4:

A complete flare was placed in a launcher 5 feet above the ground and fired normally. After ejection the flare was positioned, by pulling the parachute. The flare was extinguished using a 6 foot fog applicator with a pump pressure of 100 psi.

Test No. 5:

A complete flare was placed inside a styrofoam shipping container and armed. The lanyard was pulled, the can ejected from the container, leaving the candle inside the styrofoam container. The flare was extinguished using a 1 1/2 inch all-purpose nozzle on a 1 1/2 inch hose line with a pump pressure of 100 psi. The all-purpose nozzle was kept in full fog position.

Test No. 6:

A pyramid stack of 10 complete flares was banded together. The stack was placed so that the candle ends were against a solid surface. The center flare, (See Figure No. 3) was armed and fired. The burning stack of flares was attacked with a 1 1/2 inch all-purpose nozzle on a 2 1/2 inch line. Pump pressures of 100 to 150 psi were used.

Data collected during tests:

1. Amount of water used.

2. Hydrogen gas readings.

3. Time from start of attack to extinguishment.

4. Effective range of extinguishing devices.

5. Effective operating pressures and techniques of attack.

Test Results: Test No. 1*

Extinguishing Unit	No. Attempts	Extinguished	Time	Amount Used	Hydrogen Reading
2 1/2 gal., Press. Water	4	0	-	2 1/2gal.	0%
2 1/2 gal., Press. Water**	1	1	28sec.	2gal.	0%
2 1/2 gal., Antifreeze	2	0	-	2 1/2gal.	0%
2 1/2 gal., Antifreeze	2	2	27 1/2sec. 28sec.	2gal.	0%
2 1/2 gal., Handpump	1	0	-	2 1/2gal.	0%
15lb. Carbondioxide	1	0	-	15 lb.	0%
30 lb. Met-L-X	1	0	-	30 lb.	0%
1 1/2" All Purpose Nozzle	3	3	3 to 6sec.	Not Calc.	0%
4gal. Bucket	1	1	Immed.	4gal.	0%

* Examination of 1/4" steel plates after tests revealed no damage.
** Candle restrained 45° from horizontal with sand bags.

Test No. 2

Extinguishing Agent/Method	No. Attempts	Extinguished	Time	Hydrogen Readings
12 gal. G.I. can	1	0	-	0%
55 gal. drum candle up	1	1	35 sec.	0%*
55 gal. drum candle down	1	0	-	0%
55 gal. drum candle up	2	2	40 sec.	0%
Water added from fire hose				
55 gal. drum candle down	2	2	40 sec.	0%
Water added from fire hose				

*Reading of 0.05% in bubbles; 0% reading in air space within drum.

Test No. 3

Extinguishing Agent/Method	No. Attempts	Extinguished	Amount Used	Time
2 1/2 gal. Press. Water	3	3	1 qt.-1/2gal.	3 to 6sec.
1 1/2" all purpose nozzle on solid stream @ 20 psi	2	2	Not calculated	2 sec.
1" fog nozzle on 6' applicator @ 70 psi	1	1	Not calculated	2 sec.
1" fog nozzle on 6' applicator @ 80 psi	1	1	Not calculated	3 sec.
1" fog nozzle on 6' applicator @ 125 psi*	1	1	Not calculated	12 sec.

*Twelve second extinguishing time due to tendency of candle to turn away from nozzle.

Test No. 4

Candle was extinguished in 3 seconds with 1" fog nozzle on 6' applicator at 100 psi.

Test No. 5

Candle was extinguished in 26 seconds with 1 1/2" all purpose nozzle in full fog position at 100 psi. Delay in extinguishment was due to failure of plastic insert to separate from burning end of candle, thus preventing fire fighters from directing the fog into the end of the burning candle.

Test No. 6

Extinguishment was not achieved, but burning was controlled so that firemen could approach within 5 feet of stack. Failure to achieve extinguishment before total burnout was attributed to protection provided burning candles by aluminum cases.

Conclusions: The tests clearly demonstrated that:

1. water, either salt or fresh, is the most effective extinguishing agent for Mk 24 flares. All other extinguishing agents were unsuccessful.

2. dark goggles, preferrably shade #5 or 6, must be worn to see the flare clearly.

3. the fire fighter must be free to maneuver.

4. the flare can safely be positioned using the parachute and shroud lines.

5. the flare can be safely approached with the all-purpose nozzle, fog applicator or 2 1/2 gallon water extinguishers.

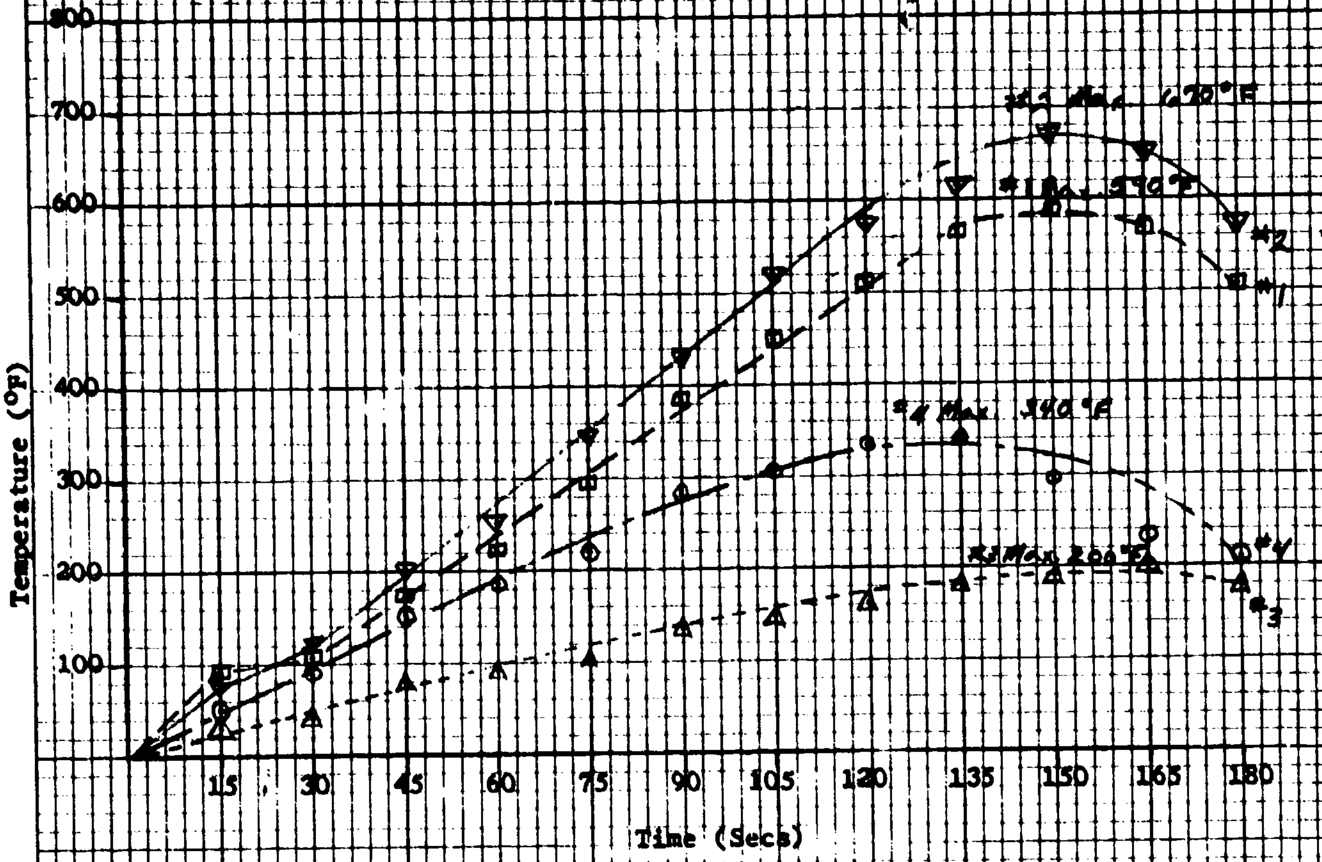
6. multiple flare fires in the open can be controlled with a single hose line, but due to the protection offered by partially burnt aluminum containers, are difficult to extinguish.

7. flares will not burn through 1/2 inch steel plate or the sides of a 55 gallon steel drum.

8. the all-purpose nozzle, on full ȝ to reduce stream pressure, and fog applicator are the most ɛffective fire fighting tools.

9. hydrogen gas generation was not a significant factor during our tests. During the dunk tests, hydrogen levels of 0.05% were detected in the bubbles. Hydrogen gas readings were negative during all other tests.

10. even small amounts of water, when applied directly to the face of the candle, will extinguish Mk 24 Flares.

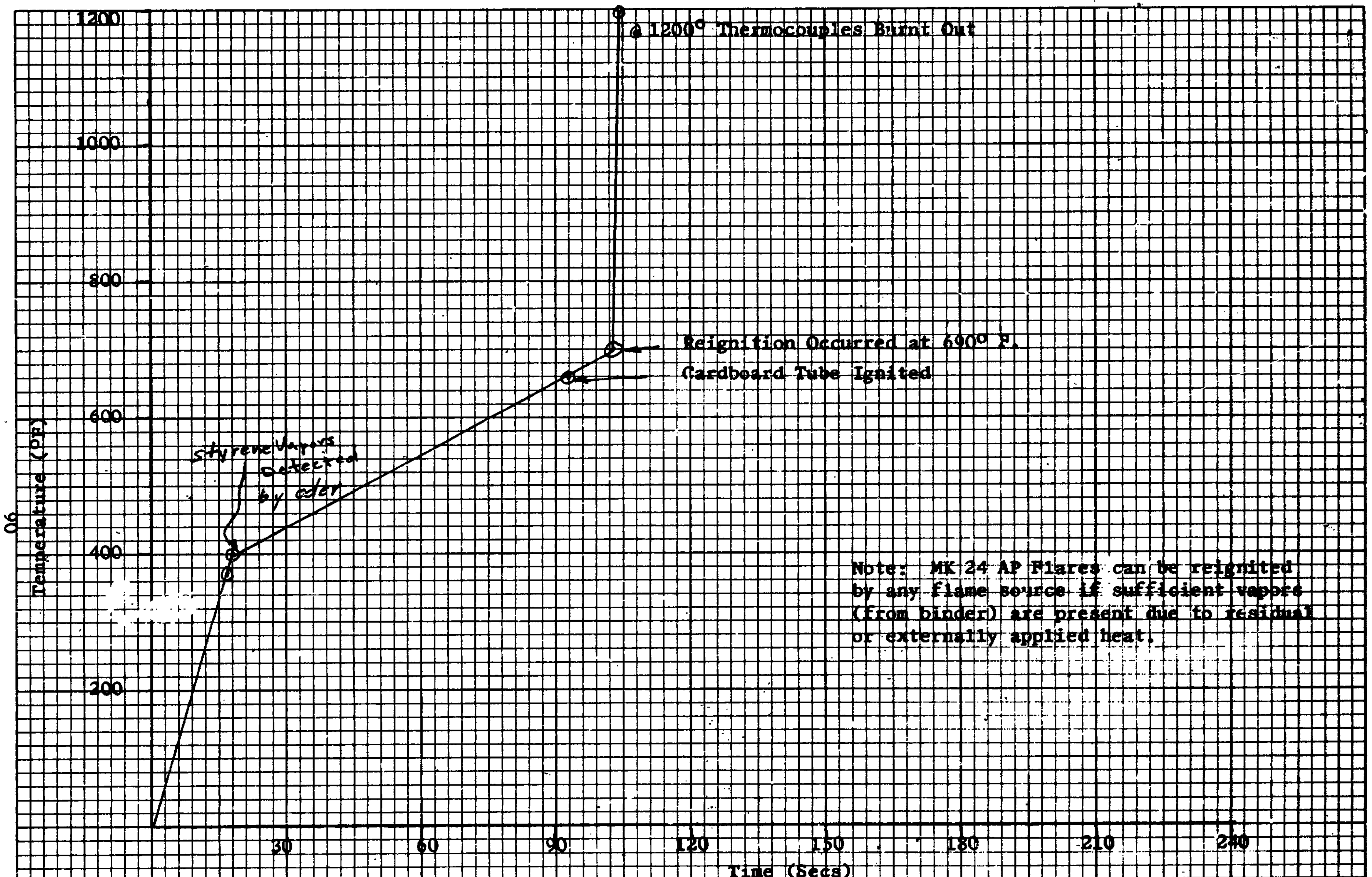


#1 - Thermocouple 6' from flare
#2 - Thermocouple 8' from flare
#3 - Thermocouple 10' from flare
#4 - Thermocouple 12' from flare

Test conducted inside steel gun mount. Thermocouple #4's high reading behind due to rebound from steel wall one foot away.

All readings within range ordinarily encountered in fire-fighting. Direct approach to burning flare should be possible.

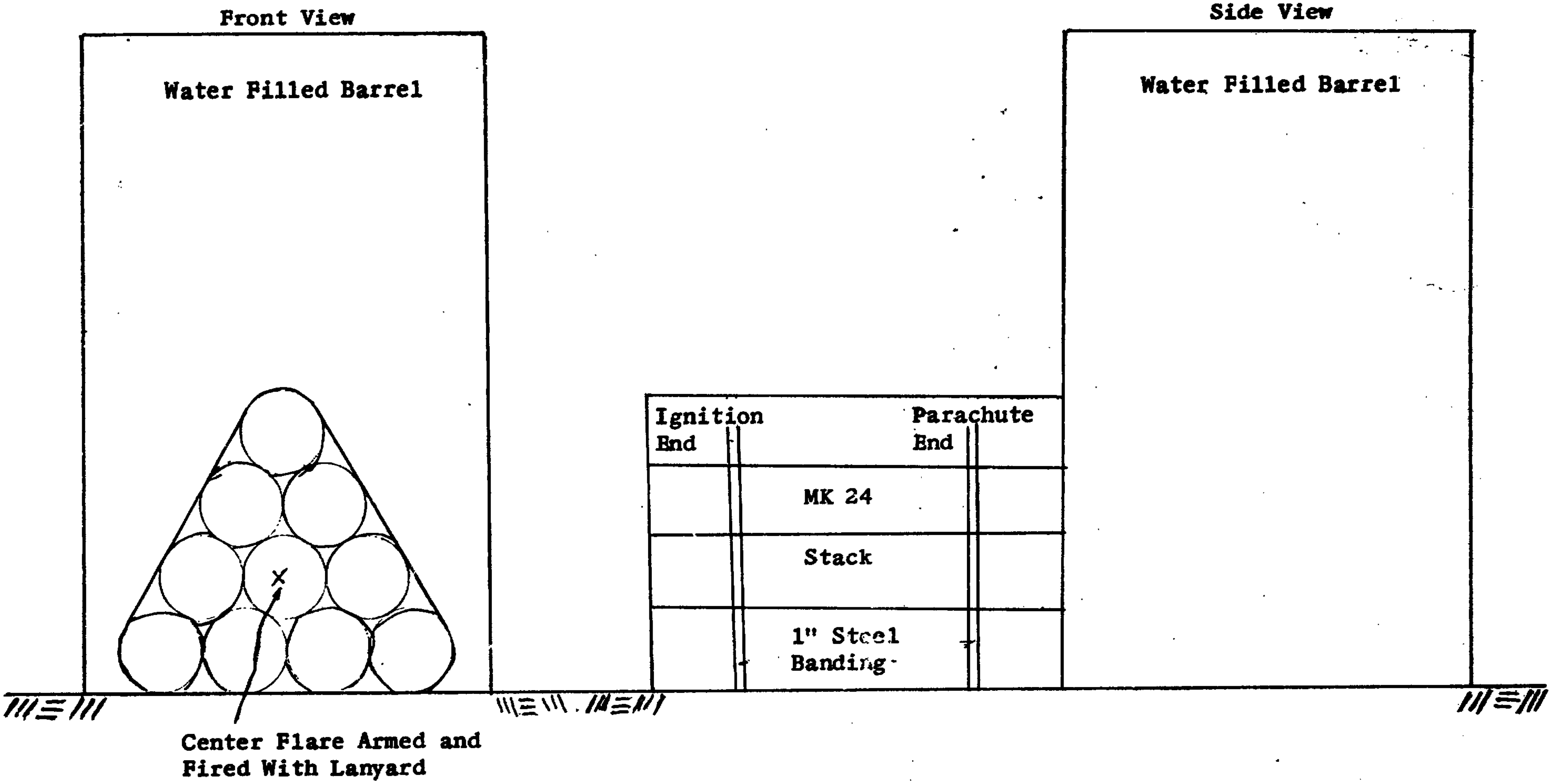
Figure 1



Reignition Temperature MK 24 AP Flare

Figure 2

Test No. 6



Drawing No. 1 (not to scale)

J. A. MILLER, OLIN MATHIESON: Has anything been looked at in the direction of this deluging of the mixer using a light sensing starting head?

CARPER: Yes, that hood that you saw in that last ball of fire was equipped with a light sensitive diode. The problem being that you're depending upon a different system of actuating your extinguishing mechanism vs an explosive valve or something like this. We've found it to be that although the sensor itself is rather effective, the system that goes with it is not so good.

A. HEESEMAN, WYLE LABORATORIES: Have you tried a cryogenic liquid to put this out?

CARPER: No we have not. We tried CO_2 and Metallex at extremely high pressures and with modified nozzles and these were totally ineffective. As a matter of fact, they would not even penetrate the fireball. They simply aggravated it and seemed to agitate the ferocity of the fire.

PANEL

THE BARRICADE QUESTION: WHAT WE KNOW AND WHAT WE DON'T KNOW

Preliminary Remarks
by
Mr. R. G. Perkins
Armed Services Explosives Safety Board

During the next session we are going to explore the subject of barricades a little in the light of recent work that has been done. We will try to present in a fair and unbiased manner some industry viewpoint, some DoD policy, and may accidentally include some personal opinions. The latter only, of course, may brand the panel as disputatious individuals.

Barricades, in one form or another, have been in the explosives safety game for a long while - more than sixty years in some regulations. As you know, quantity-distance regulations generally provide for differing levels of protection depending upon the target presented. These are usually intermagazine distance, intraline distance, and inhabited building distance. Also, public railroad and public highway distances may be specified where applicable.

For most situations and all of these levels of protection, regulations usually provide for greater distance requirements without a barricade than when one is present. Furthermore, historically this increase has been established in many cases as a requirement that the distance be doubled if the barricade is not present.

Barricades vary, legally within accepted definitions, from flimsy structures easily destroyed by a fraction of the explosive to which exposed, all the way up to massive terrain features that would be only moderately affected by atomic blasts. No differentiation is apparent in the regulations, however, for such wide variations in situations.

The cost of providing standard barricades may be of monumental proportions. In some cases, it can easily out-distance the cost of the source explosion or the target building - might even equal their combined cost. On the other hand, ever increasing amounts of explosives, numbers of buildings, and real estate values mean that land acquisition costs may become impossibly high unless the soundest approach practicable is used to evaluate the regulations with respect to barricading.

These considerations have prompted the Board to sponsor or support work aimed at providing more valid information with respect to the barricade problem and information in some areas where none or very little

formerly existed. The results have been quite interesting. The material to be presented by this panel is not intended to be unnecessarily controversial, we welcome, however, some controversy when it is such as to develop further technical information that is based on valid data and not on passion and emotion.

THE BARRICADE QUESTION:
WHAT WE KNOW AND WHAT WE DON'T KNOW
WE MUST SEPARATE FACT FROM FOLKLORE

by
Mr. William S. Filler
NOL White Oak, Silver Spring, Md.

ABSTRACT

Present barricade usage for the most part is based on vague and often incorrect intuitive assumptions. This is borne out by a recent comprehensive study of accidental explosions that showed that barricades did not reduce damage to adjacent buildings in any significant way. This result confirms earlier limited studies and is consistent with established knowledge on the diffraction of blast waves about obstacles. Also, since it was found that barricades are often destroyed in accidents, their role as a secondary fragment source must be considered along with their role as a primary fragment stopper, if their effectiveness in reducing fragment damage in general is to be properly evaluated. While barricades undoubtedly have value under some circumstances for preventing explosion propagation and possible injury to personnel, the conditions for obtaining such benefits are not now known in terms of quantitative ranges of blast, fragmentation, or other effects of explosions. Explosive storage problems must be studied in the light of available knowledge of the physical effects of explosions in order to know what loads protective construction must withstand and thus whether it is technically feasible and economically desirable to provide some selected degree and type of protection. Much information of the type needed is already available and needs only to be applied. Other needed information can be obtained by means of analytical and experimental techniques already in established use for explosives applications.

Not too long ago, Joseph Rossi of the Picatinny Arsenal Safety Office, Harold Walsh, a civil engineer then with the Air Force Weapons Laboratory at Kirtland Air Force Base, and myself were requested, at the initiative of the Armed Services Explosives Safety Board, to examine reports of accidents involving explosives and to see what could be learned about how effective barricades may have been in reducing damage and injury.

We spent about four months surveying all the accident reports we could find, not only in the Department of Defense, but in industry as well. We collected a great amount of damage data and, along with other analyses, developed a technique to determine the extent to which barricades were effective in reducing damage to buildings.

It is basically a statistical method in which all instances of damaged buildings are grouped in five categories, as shown in Figure 1, according to the degree of damage. These categories are:

A - Demolished (Not standing)

B - Severe Damage (Standing, but substantially destroyed, some walls gone)

C - Moderate Damage (Walls bulged, roof cracked or bulged, studs and rafters broken)

D - Slight Damage (Doors, sashes, or frames removed; plaster and wallboard broken; shingles or siding off)

E - Minor Damage (Broken glass or miscellaneous small items - similar to that resulting from a high wind).

This was done for accident cases where the weight of explosive material involved was known and the distance from explosion to the damaged building was given. In accordance with the weight scaling law for explosives, we divided the distance by the cube root of the weight to obtain a reduced distance that permitted us to treat all the building damage data as though the weight of explosive were the same in all the accidents. This reduced distance is the vertical axis of Figure 1. The data in each category have been separated according to whether the structure was barricaded (BAR) or not (UNBAR). Now, while the data are quite scattered, in each category of damage the median or center of mass, so to speak, is located (triangular marks) at about the same distance for the barricaded as for the unbarricaded data. If barricading were as effective as the double distance rule implies, then one would expect the median for unbarricaded data to be located at twice the barricaded distance as shown by the circular mark in each category. As you can see, the lack of support for the double distance rule is quite clear in spite of the scatter of this data.

We also calculated average distances for the data in each damage category and then for all data combined. Within a sigma or standard deviation of ±11%, again no differences were found between barricaded and unbarricaded data.

This result should come as a surprise to no one, for during the last world war, two other studies of this type, one by Robinson and another by Wollman but of more modest proportions, came to similar conclusions. This was also a conclusion of the Arco, Idaho study of 1946. From a physical or blast aerodynamics point of view, again, this result is no surprise. For the behavior of a blast wave has long been known to be analogous to a wind that builds pressure on the front side of an obstacle but proceeds to envelop and reform after a short distance beyond the back side. It is then ready to wind-load, so to speak, the next obstacle with no significant loss in pressure. Present regulations that give distance-credit for barricades are based on the gross misconceptions that blast behaves like a fragment--once stopped, that part of the blast wave is supposed to be permanently out of the picture so far as damage goes. This is a very naive concept at best.

The study that we conducted also revealed that a high percentage of barricades was destroyed when accidents occurred and that such destruction often took place for quantities of explosive well below the maximum permitted amount for the barricade. Fragments generated by these destroyed barricades introduce uncertainties as to the effectiveness of barricades in reducing overall fragment damage. The question of explosion propagation from one site to a second by high speed fragments is obscured by this fact and it does not seem possible to learn much about this from studies of accidents. This leaves us with the need for more information on the requirements for the prevention of propagation of explosions.

But requirements for protection must be defined and considered from a broader perspective. From the point of view of physical effects the following must be considered:

1) Barricades are now used for protection against a great variety of circumstances associated with accidental explosions. They are used to reduce damage by fire, fragments, and blast, as well as to prevent propagation of detonation by any of these means. When located adjacent to an explosives site, they are intended to reduce damage and injury in nearby buildings. They are intended to serve that same purpose when located near a building not itself the source, but in the neighborhood of an accident. Certain types of explosives-containing structures such as igloos and magazines of various types are considered barricaded, per se, while certain natural terrain features such as hills may also be considered effective barricades.

2) Each type of situation identified above must have a distinct group of phenomena and associated magnitude ranges that would be involved should an accident occur. For example, explosive weight scaling and the many orders of magnitude range in pressure are characteristic features of a high explosive blast over its damage life cycle that are of overriding importance so far as

protective design for specific purposes is concerned. Similarly, fragment velocities, fallout density, and maximum range are intrinsically ballistics problems, and if studied in that light, might yield valuable insights on the role of barricades and on damage from accidental explosions, generally. Yet, there is a dearth of engineering analysis, data, or design criteria relating barricade structural features to explosion phenomena in a quantitative way.

At my laboratory we have a 10 x 10 foot test cubicle with two-foot-thick reinforced concrete walls and ceiling. The maximum quantity of high explosive allowed to be set off inside the cubicle is only 5 lbs. Outside the cubicle is barricade whose dimensional and material features generally are no different from those used in the recent "Big Papa" test in Utah where 250,000 lbs. of high explosive bombs were detonated. In Utah we are trying to prevent propagation from one pile of bombs to the next. At NOL we are trying to prevent human injury. Now, it may be that current barricade usage has such universal and wonderful capability. What is disturbing is that no single or collected body of principles, data, design criteria, or methods for relating the function to the design (that is, the protection desired from a certain type and amount of high explosive to the structural design) is available to a civil engineer about to design a new facility. There are, of course, rules that specify what the shape of the barricade should be so it will not erode too much over the years. And there are quantity distance tables that tell how close the nearest inhabited building should be. But not very much else.

Barricades are like some of the ancient medical remedies that have come down to us through the ages. Belladonna for example is a muscle relaxant and is still unsurpassed for certain types of stomach ailments, but no doctor today would knowingly prescribe it to cure appendicitis or ulcers or cancer. A hundred years ago a doctor might have gotten away with it, but probably not his patient.

I believe we have an analogous situation today with regard to barricades. We now know much more about the effects of explosions (the diseases) than we did when barricades came into use. And we know that a barricade like belladonna does some good in certain circumstances. But we have been somewhat negligent in defining these circumstances in the light of contemporary knowledge. Much of our present usage in regard to barricades is frequently inadequate and too often totally inappropriate. We have also been negligent in applying contemporary knowledge of explosion effects to accidental explosions. As a result we have clung to time-honored if otherwise disreputable concepts of protection. We have continued to act as if barricades had magical ability to reduce damage and injury under any and all circumstances. I use the word magical deliberately because I have been hard put these last few years to turn up literature that could be dignified with the adjective scientific or engineering and that purported to relate the specified functions of barricades in a general sense to established technical data on explosion phenomena --although there have been individual buildings designed for blast loading.

Now turning to the question of what to do about this situation I return to my medical analogy. The most vigorous research program on the nature of belladonna and its effects on humans is not likely to be of much help in revealing a cure for stomach cancer. In the same sense the detailed study of barricade shape and composition is of little use in determining what protection is feasible for the great variety of explosive storage situations. We must study the diseases themselves, that is, we must estimate the type and magnitude, and physical effects (blast, fragments, etc.) of explosion that are likely to occur should an accident take place in a particular facility. Then we must consider the cure: what is a reasonable approach to protection of people -- nearby, far away, in a plant, outside; and to protection of material -- explosives or equipment, and these in relation to their military and economic importance.

The very word barricade should be discarded because it encompansses a collection of things too diverse physically to be usefully related. In its place we must substitute the idea of protection from explosion effects and related concepts of protective construction. Each type or class of situation (once these are established in terms of physical effects and engineering design requirements) must be dealt with as a distinct problem, and analyzed in terms of physical and engineering data that is now available.

The pyramids of Egypt are good examples of wonderful ancient structures built without benefit of modern sophisticated technical knowledge. They even look something like barricades, and like barricades they certainly have stood the test of time so far as durability is concerned. But unfortunately, again like barricades, little of their function is known.

Fortunately for us we are in a good position today with respect to information and data on the physical effects of explosions. We know a great deal about the blast wave from an explosion and the force it generates on structures, how it reflects and diffracts around objects.

Where quantitative information is missing we have good methods available that can very likely provide reasonable answers or at least a conservative upper limit for any given problem.

Since World War II the great strides made in our understanding of explosion effects have led to comprehensive studies of means for protecting against the effects of nuclear explosions. Yet, only limited or piecemeal efforts have been made to apply fundamental effects information to problems of protection from accidental chemical explosions.

In recent years, simulation techniques for studying fundamental as well as applied or engineering problems involving blast using small scale explosions and shock tubes have been developed to a high degree. Computer methods have been developed for solving in a readily usable and, where appropriate, in a graphical fashion, the complex hydrodynamic equations governing explosive detonation, fragment acceleration, blast propagation, and the loading of structures. Analysis and application of the basic blast

and fragmentation literature, the use of computational methods and the employment of simulation techniques are powerful ways of obtaining solutions to many practical problems.

At the same time, it is recognized that full-scale confirmation of results obtained on a small scale is necessary in certain instances as a final step before safety standards can be based on the information obtained. An approach involving preliminary as well as parallel analytical and small-scale experimental studies would be similar to that used with great success in the past by the AEC in connection with nuclear explosion tests. What is called for is a well financed effort by technical people who can make effective use of available knowledge to improve our ability to provide protection from the effects of accidental explosions.

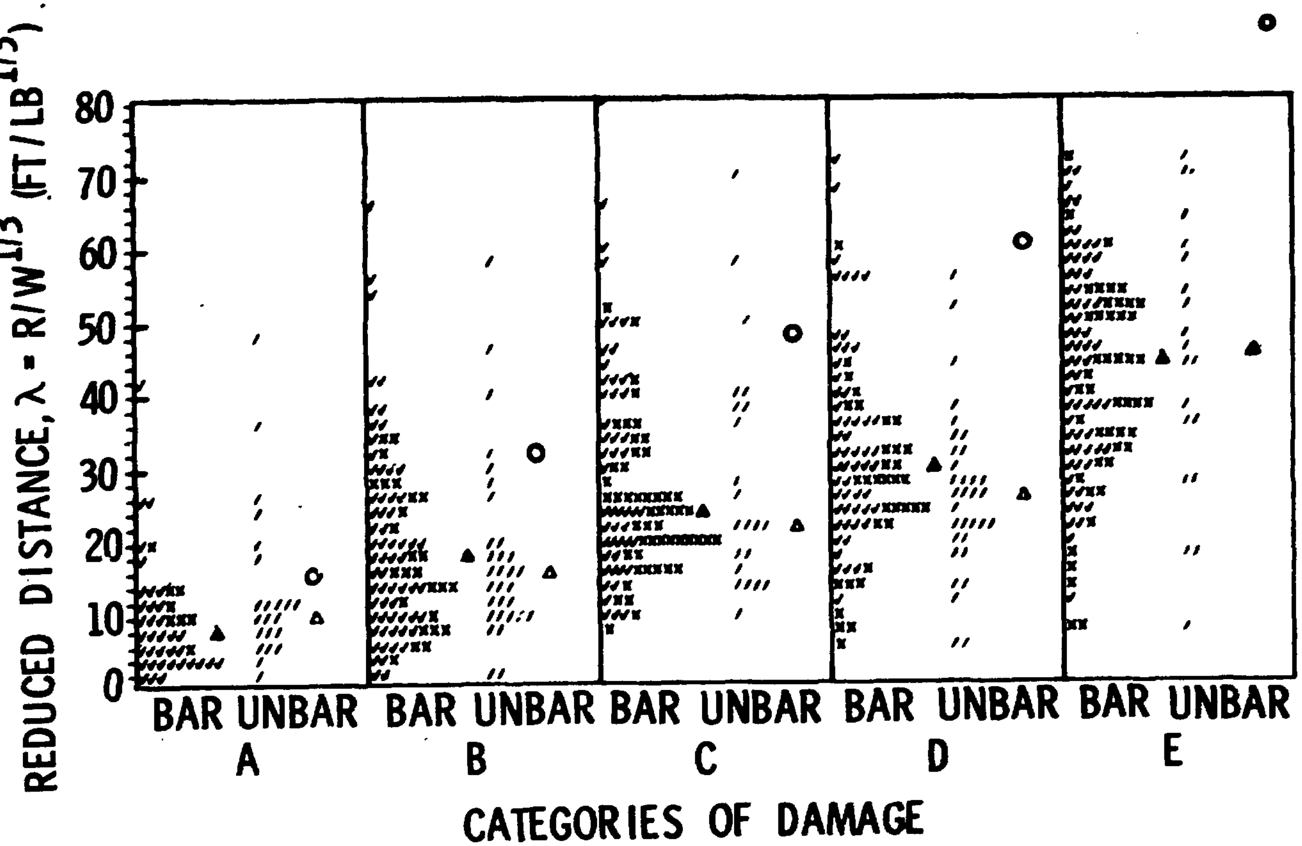


Figure 1. Scatter Plot of Damaged Building Items.
Degree of Damage Versus Reduced Distance.
Unbarricaded (/) Items Are Separated From Barricaded (✓) Ones.
Items With Two Barricades, One at Source and One at Target,
Are Marked (X).

BARRICADE USE AND EXPERIENCE IN INDUSTRY

by
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Hercules Incorporated
Wilmington, Delaware

The industry's consensus on the value and use of barricades is expressed in the "quantity-distance tables" contained in various manuals of safety practice used by the military. The tables assert distances from an explosion at which certain specified levels of damage are a probable risk. They are broken into the following four categories:

(1) Inhabited Building Distance
(2) Public Highway and Railway
(3) Intraline
(4) Intermagazine

For each of the four defined categories and for certain related situations, industry's practice is to consider that barricades reduce the risk from mass-detonating explosives at a given distance. American quantity-distance tables incorporate this by specifying a different spacing for barricaded and unbarricaded facilities. When barricades are not present, the spacing listed is double that required in a similar category with barricades. There are certain approved designs for barricades. Their dimensions and orientation relative to the positions and shape of the other facilities is specified. However, in general, the design specifications are not dependent upon the weight of explosive. Except in a limited sense, and in the case of storage igloos, the distance does not depend on whether the site, the target, or both, are barricaded. If two structures are spaced at the unbarricaded distance or greater, no barricades are needed; if spaced less than the full unbarricaded distance, at least one barricade, as specified, must exist between them. There is no accepted standard in industry for designing protective structures or barricades to better resist the effects of an explosion, such as a remote control shelter, where a greater level of protection is essential at a given distance than that accepted by the quantity-distance tables, or where a structure must be located closer to the potential source of explosion than the barricaded distance.

Industry uses quantity-distance tables for mass-detonating explosives and assumes that barricades furnish protection over a wide range of weights of explosives and distances, and against a variety of damage mechanisms. The mechanisms include blast pressure, blast impulse, the spread of missiles, and the spread of fires. The construction of the barricade and the manner in which it is assumed to furnish protection does not change in accordance with explosive weight, actual or scaled distance, or damage mechanism.

INDUSTRIAL EXPERIENCE

In the Work Group Report published in July of 1966 by ASESB entitled "Barricade Effectiveness Evaluated From Records of Accidental Explosions", the Work Group summarizes industry's experience in the use of barricades. In a review of explosions in which the barricades at the source of the explosion were well described, an attempt was made to determine the extent to which each type of barricade survived explosions of various sizes. The pattern of failure or damage to the barricade was of particular interest, as well as the weight of explosives causing complete destruction. The extent that a barricade survived appears to depend, as might be expected, (1) on its construction, (2) on the extent to which the source was confined by barricades, and (3) the weight of the explosive. For the purposes of this discussion, barricades are considered to be of five types:

1. Double Revetted, sometimes called the Crib or Rapauno.
2. Single Revetted
3. Natural Barricades
4. Intervening Terrain Features
5. Igloos (or earth covered structures)

1. Double Revetted Barricades (Figure 1)

Weakest of all barricades are the double revetted. These are walls of soil held between a nearly vertical sheeting of wood or concrete on each side, so that their top is typically three feet wide, the base 12 feet wide for a wall 20 feet high.

(Figure 2) When explosions took place, damage to the double revetted increased with explosive weight and followed a certain pattern. The least damage consisted of breaking and disordering of the interior facing, together with erosion of the earth behind it to some depth down from the top. The exterior facing also was broken off, usually being completely gone for a greater distance down from the top than the interior facing. Thus, the soil was left with an upper surface that sloped steeply downward from the inner to the outer face. As the damage level increased, the depth of this soil surface came further down, until finally the barricade was gone completely down to ground level or below. The damage varied with the distance of each part of the wall from the explosion. Often the middle parts of straight walls were completely gone while the corners largely remained.

When an explosion was surrounded by barricades on all sides, the greatest high explosive blast that caused only small damage to the crib walls was 250 pounds, while explosions as small as 1,325 pounds completely removed them.

2. Single Revetted Barricades (Figure 3)

Another type of artificial barricade has sheeting on only one side nearer the explosive. These are called single revetted barricades. The

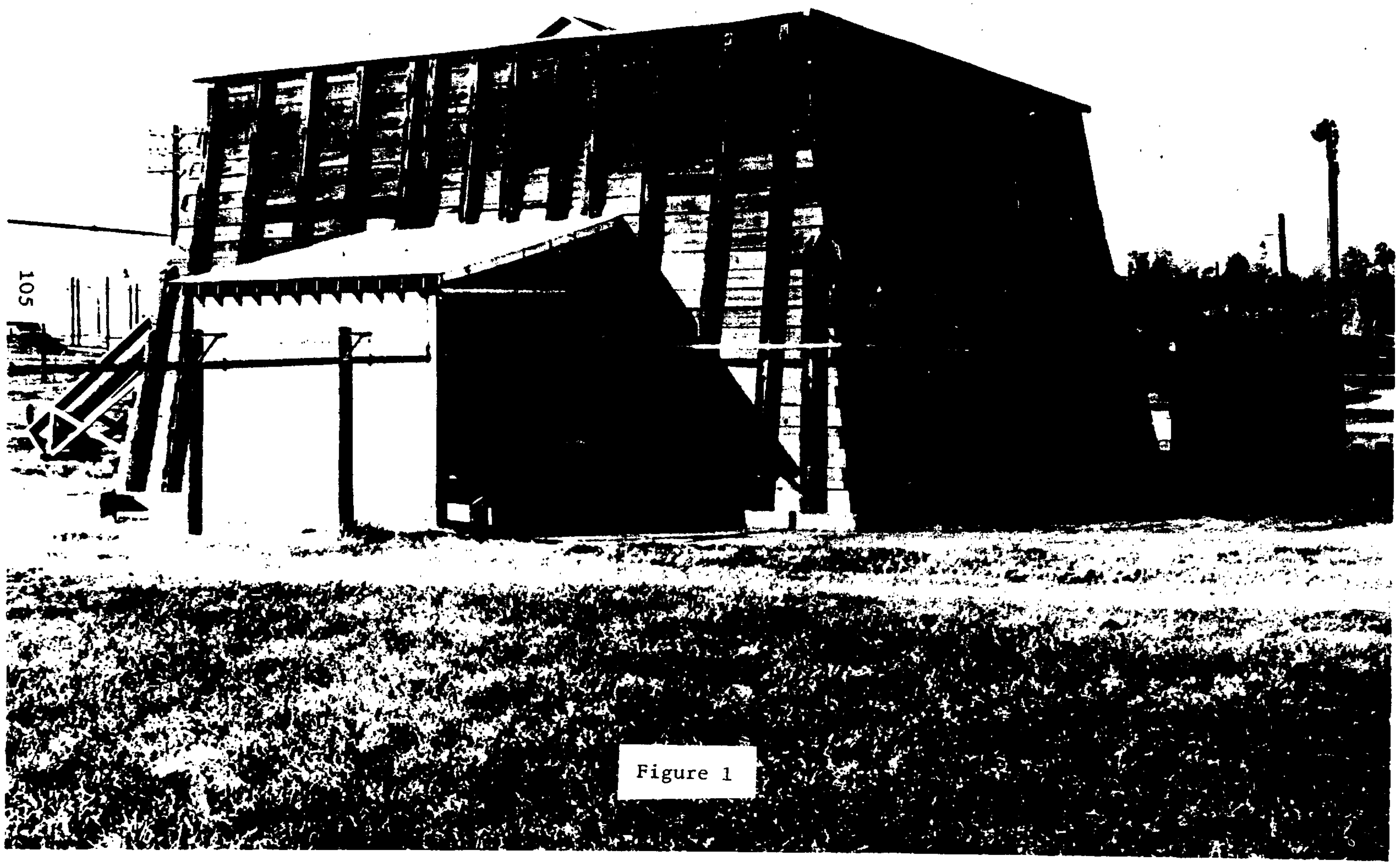


Figure 1

Figure 2

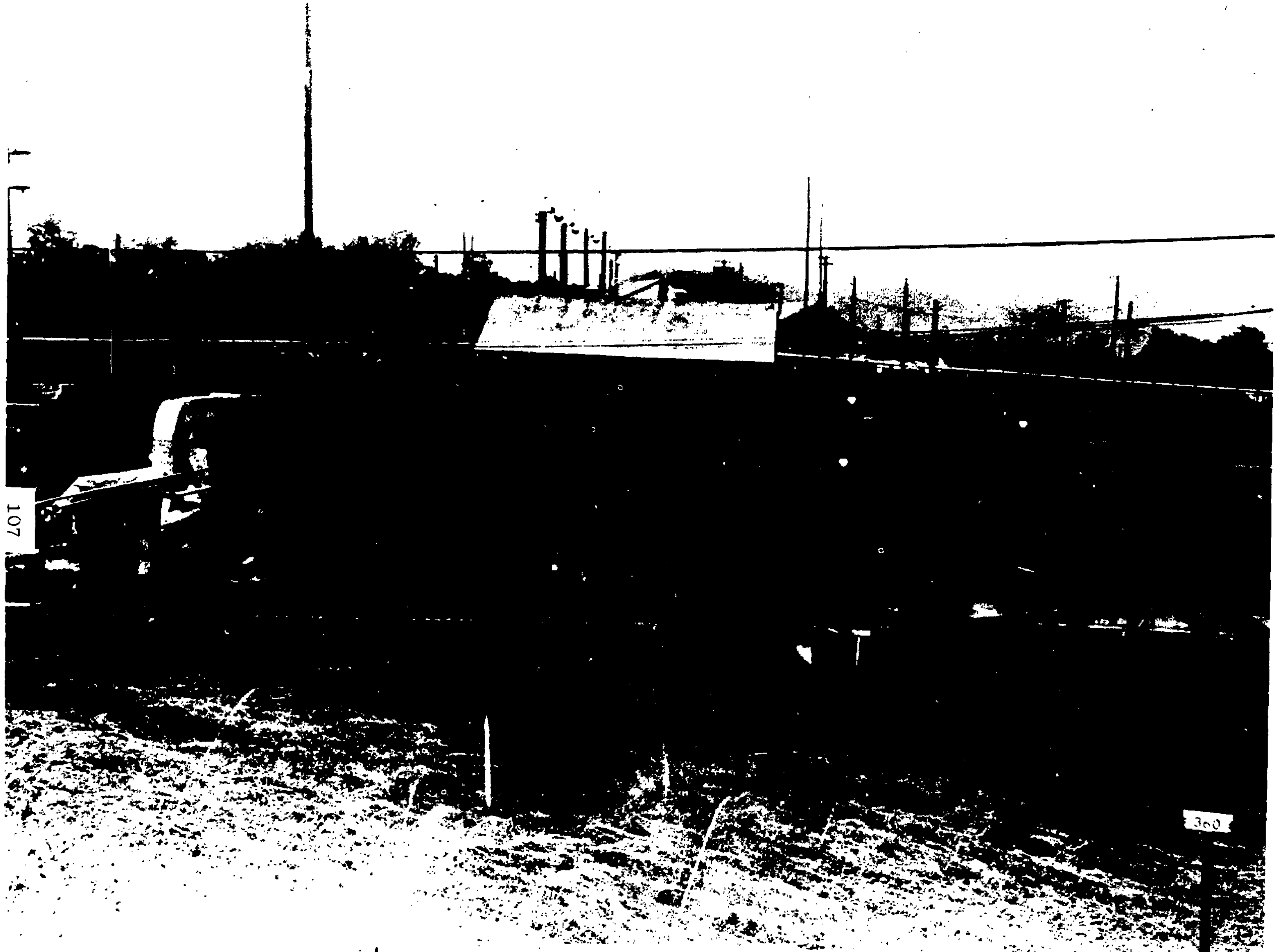


Figure 3

inner side is sheeted to a slope equivalent to that of a double revetted barricade, while the outer side is at a slope at which the available soil is stable. Thus, they are much more massive than double revetted barricades. They normally have a base approximately 45 feet wide for a height of 20 feet and a top width of three feet.

(Figure 4) Explosions caused breakage of the facing of the mounds and erosion of the earth behind the facing, just as they did when a double revetted barricade was used. The remaining part was left with an upper surface flatter than that of a crib, but still sloping down with increased distance from the explosion. As the weight of the explosion increased, the depth cut away also increased, but the upper surface became flatter until finally complete destruction was characterized by the mound being level with the ground from the inner face out to a small pile of material left in place at the far edge. Sometimes the crater extended into the leveled area.

Sufficient examples were found to relate the damage trend to charge size. Detonations of 500 pounds of high explosives produced minor erosion when another side was open or was barricaded by a double revetted barricade that blew down, but 600 pounds produced significant erosion when a single revetment fully surrounded the explosion. The upper half or two-thirds of the mound was removed by an explosion of 1,000 pounds, and as little as 1,200 pounds caused complete destruction. In some cases, most of the height survived explosions as great as 4,000 pounds, and up to 10,000 pounds if one or more sides were open; but in such cases, the records generally indicated that the explosion was at second-story level or above.

3. Natural Barricades (Figure 5)

To simplify discussion, natural barricades are limited here to those whose tops are the original ground surface and which have an inner slope with some sort of near-vertical facing. (This definition is more restrictive than in some manuals. The term "faced natural earth barricades" is used to distinguish this kind of barricade from hills or belts of trees, which are sometimes considered natural barricades.) Natural barricades often are constructed by building the structure within a level area cut into the face of a hill, the sides of the cut being nearly vertical and faced usually with concrete, or with wood cribbing. Occasionally, equivalent barricading is provided by keeping the explosive in the basement of a building on level ground or cut into a slope, the barricade facing acting as the supporting wall.

(Figure 6) Here, we are concerned with the survivability of the natural barricade, or from ground level downward. On a hillside, this would normally have one open side, one level-topped side of full height, and two sloping sides. Occasionally, the open and sloping sides are close to full height with double or single revetted barricades. It was found that the natural barricade was chewed away from the top down just as the single revetted was, but that larger detonations were required to produce this erosion. The eroded surface typically sloped upward as distance from the facing increased, much as the slope of a crater in the same soil would.

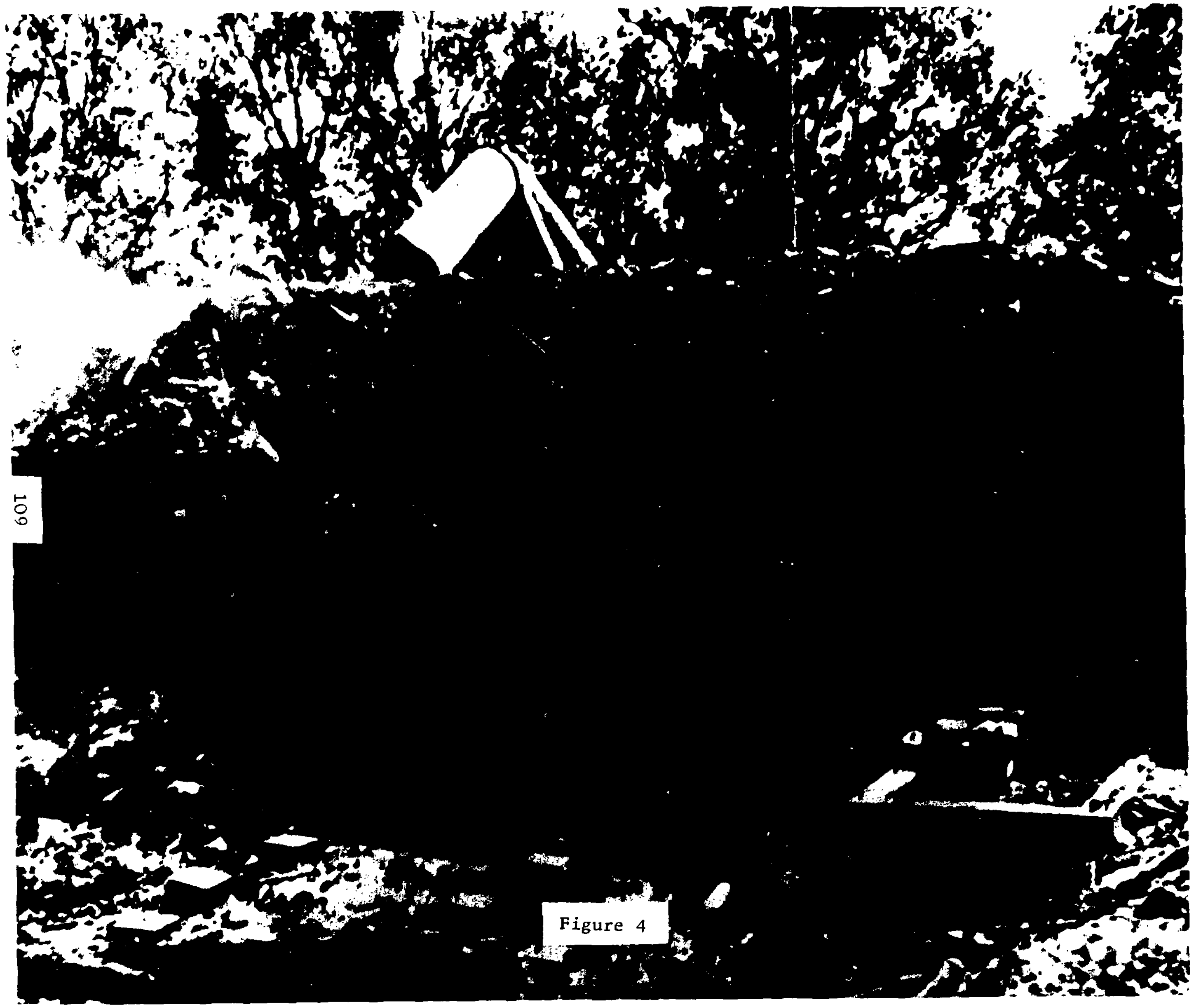


Figure 4

Figure 5

Figure 6

Below a weight of approximately 1,000 pounds of explosive, damage is limited primarily to breakage of the facing below the natural ground surface, with some throw-out. At a weight of approximately 1,000 pounds of explosive, even strong facing is disintegrated, large amounts of it are gone, and the typical crater surface has been chewed far enough down in the facing to involve some of the earth behind it. At a weight of 7,500 pounds of explosive, most of the facing is gone, and the crater surface may extend in places from the inner face near the bottom of the wall up to the ground surface. As weights increase through the range of 1,500 to 7,500 pounds, the breakage of the remaining facing and its removal or displacement from the original position become greater.

4. Intervening Terrain Features (Figure 7)

Natural hills or ridges, without alteration, and heavy belts of trees are considered to be barricades in some manuals. Although difficult to assess because of a lack of information on their original condition, some attempt was made to estimate their durability. Natural hills are usually undamaged even in very large explosions, apparently because the slope is flatter and the hill is farther from the charge than a crater surface would be in a faced natural earth barricade. Trees also appear to be fairly durable. Some which have stood as close as 50 feet to a 1,500 pound explosion, otherwise unbarricaded, have remained standing although suffering fragment damage and having many branches stripped. Unfortunately, most information on both trees and hills is very qualitative, being taken only from photographs, since few have recorded the distance to trees or the before-and-after surface of a natural hill.

5. Igloos (Figure 8)

Igloos are built for storage of large quantities of explosives that fill their volume (normally 250,000 pounds Class 7) and are not expected to survive any explosion when filled to their design weight. However, cases were found in which accidents occurred in nearly empty igloos, and from these some observations were made on their pattern of failure. In all cases, the igloos had a standard reinforced concrete circular arch as a roof, covered with a few feet of earth. Some distance above the floor, the earth fill and concrete wall become of such a width and shape that from there down they greatly resemble a mound barricade.

In even the smallest explosions, the roof was completely removed down to the point where the mound shape began. Below that point, instead of being eroded and fragmented like mounds, the igloo wall usually was shoved horizontally outward as a broken but identifiable mass, sliding on its contact with the ground surface. Often the wall moved tens of feet but remained nearly intact. Also, the floors usually were intact and without craters in those explosions where the walls were shoved out but standing. (Figure 9) For greater quantities, the site would consist only of a huge crater with hardly a trace of the floor and walls. These accidents usually involved ordnance items in crates and on skids rather than a homogeneous mass of explosives.

Figure 7

Figure 8

Figure 9

Failure in the form of roof removal and wall shoving occurred in explosions in a range from 1,150 pounds to 45,000 pounds of high explosives. In explosions of 100,000 pounds or more, however, the entire site became a crater.

(Figure 10) In recent years, at least for the past 15 to 20, industry in manufacturing areas had a tendency to get away from the double revetted barricades (Figure 11) and go to the single revetted concept, using the sides of the barricade as the side walls of the building.

(Figure 12) Even more recent (for the past ten years), there has been a trend to the earth covered buildings in operating areas to gain the additional protection afforded to target building from falling missiles. (Fig. 13)

(Figure 14) Since the 1945 and 1946 Igloo Tests at Arco, Idaho, and the Earth Covered Steel Arch Tests at China Lake in 1965, industry is going more and more to earth covered construction, (Figure 15) (1) to gain the additional protection offered from falling missiles, (2) to reduce the damage from blast overpressure, and (3) to minimize chances of propagation.

SUMMARY

Experience has shown that the barricade surrounding the charge normally does not survive an incident. The debris torn from barricades may increase greatly the density of fragments.

1. However, the barricade surrounding the target buildings do minimize or prevent propagation by high velocity missiles.

2. Target buildings surrounded by barricades see a shadow effect from blast overpressure which reduces the damage and potential of propagation.

3. There are many incidents on record where personnel have been protected and their life saved by both of the above items, not only in the target buildings, but by being protected by the barricades surrounding the donor charge.

4. Barricading the donor buildings in accordance with the present manual will prevent propagation in an acceptable percentage of cases by reducing the horizontal high velocity missiles.

5. The safety manuals should be revised to reflect the current thinking of industry in the design of structures and barricades to better resist the effects of an explosion.

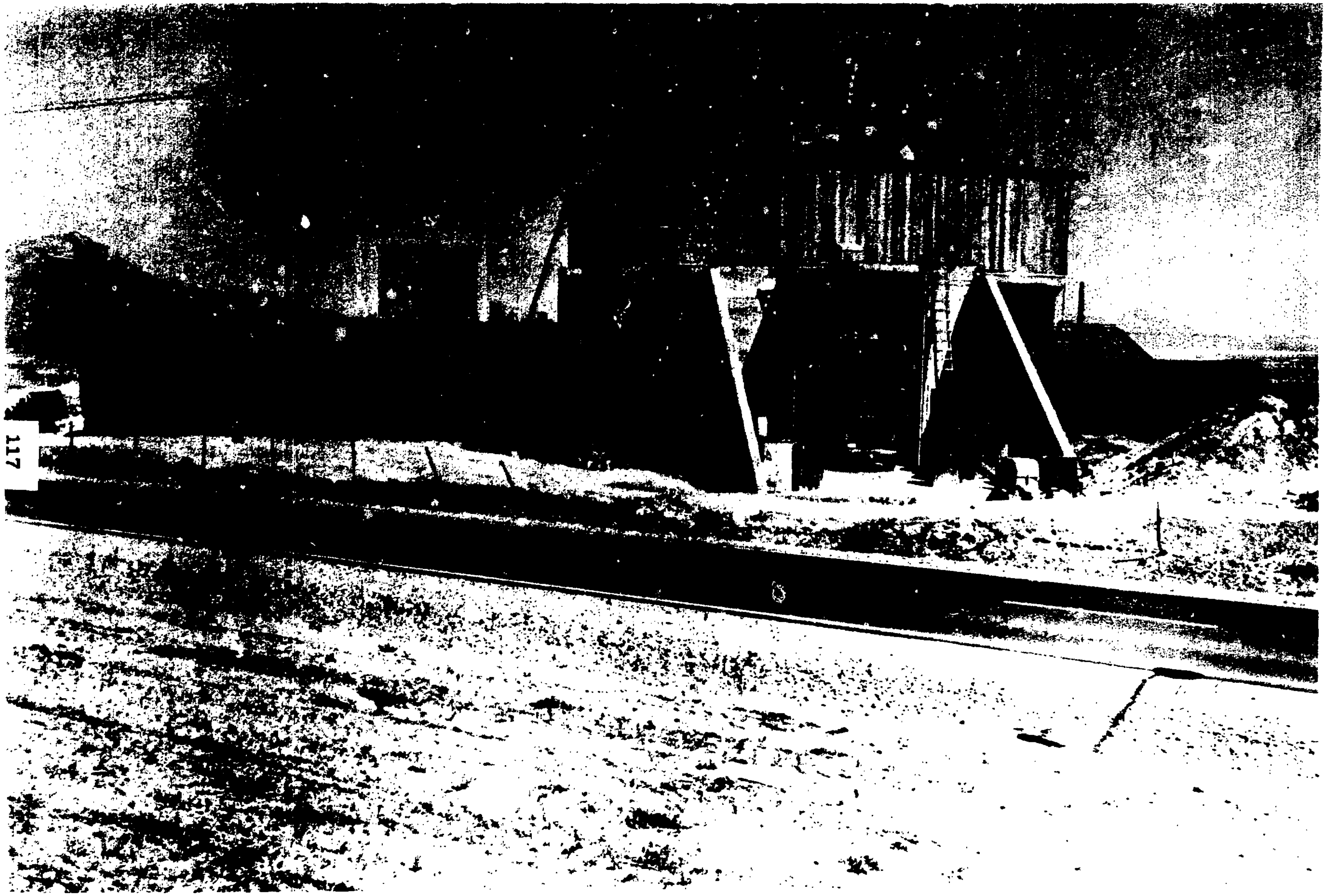


Figure 10

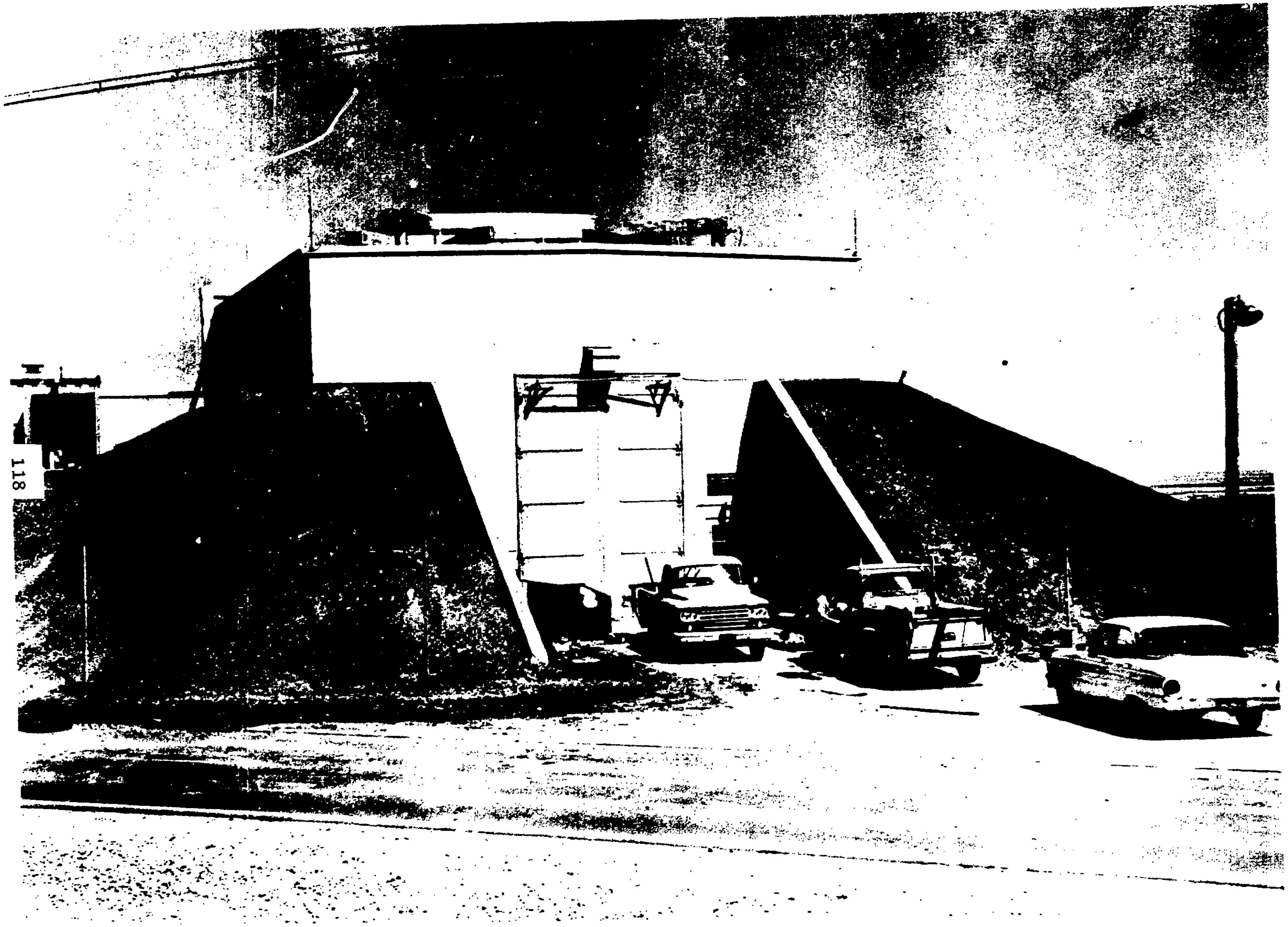


Figure 11

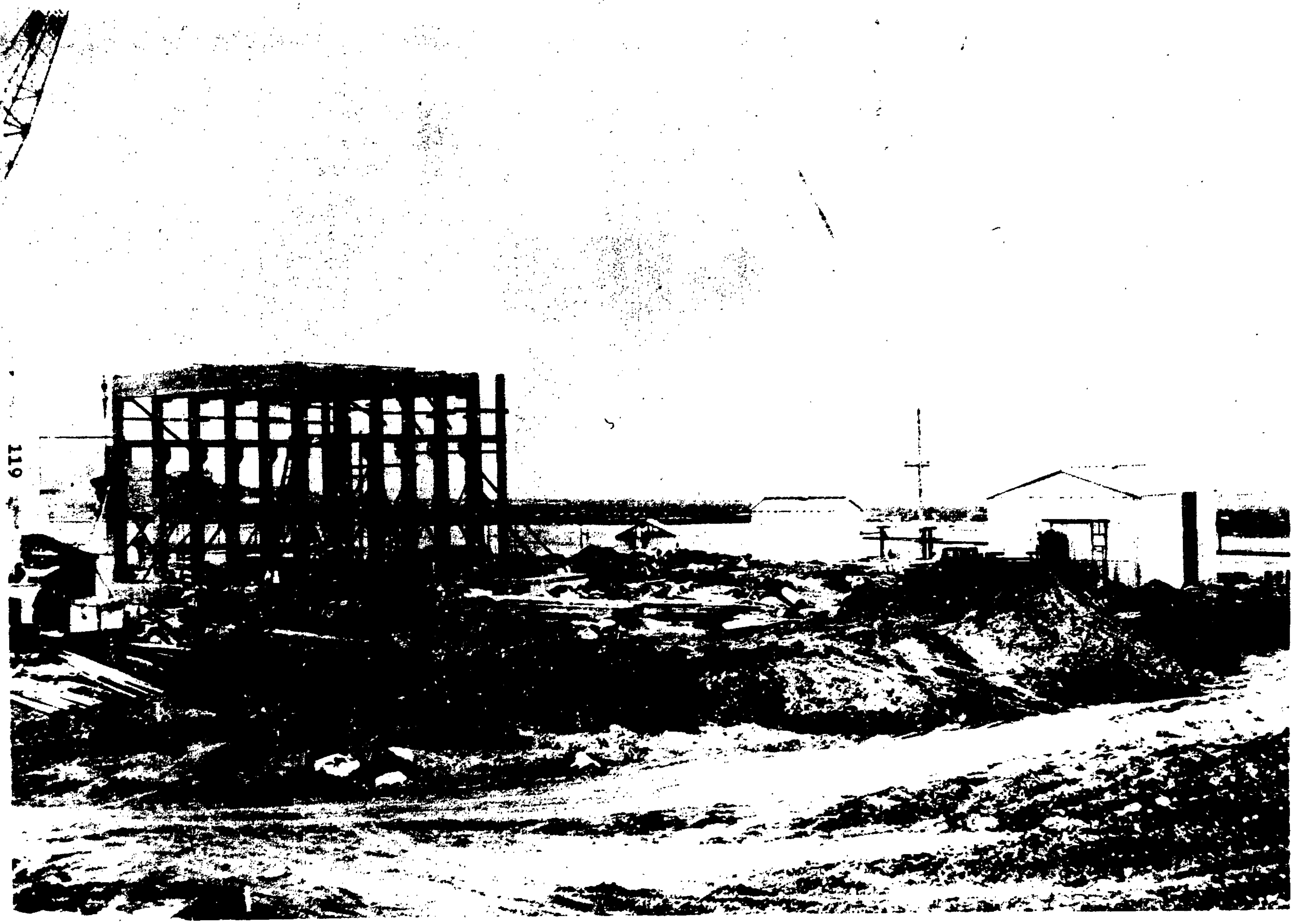
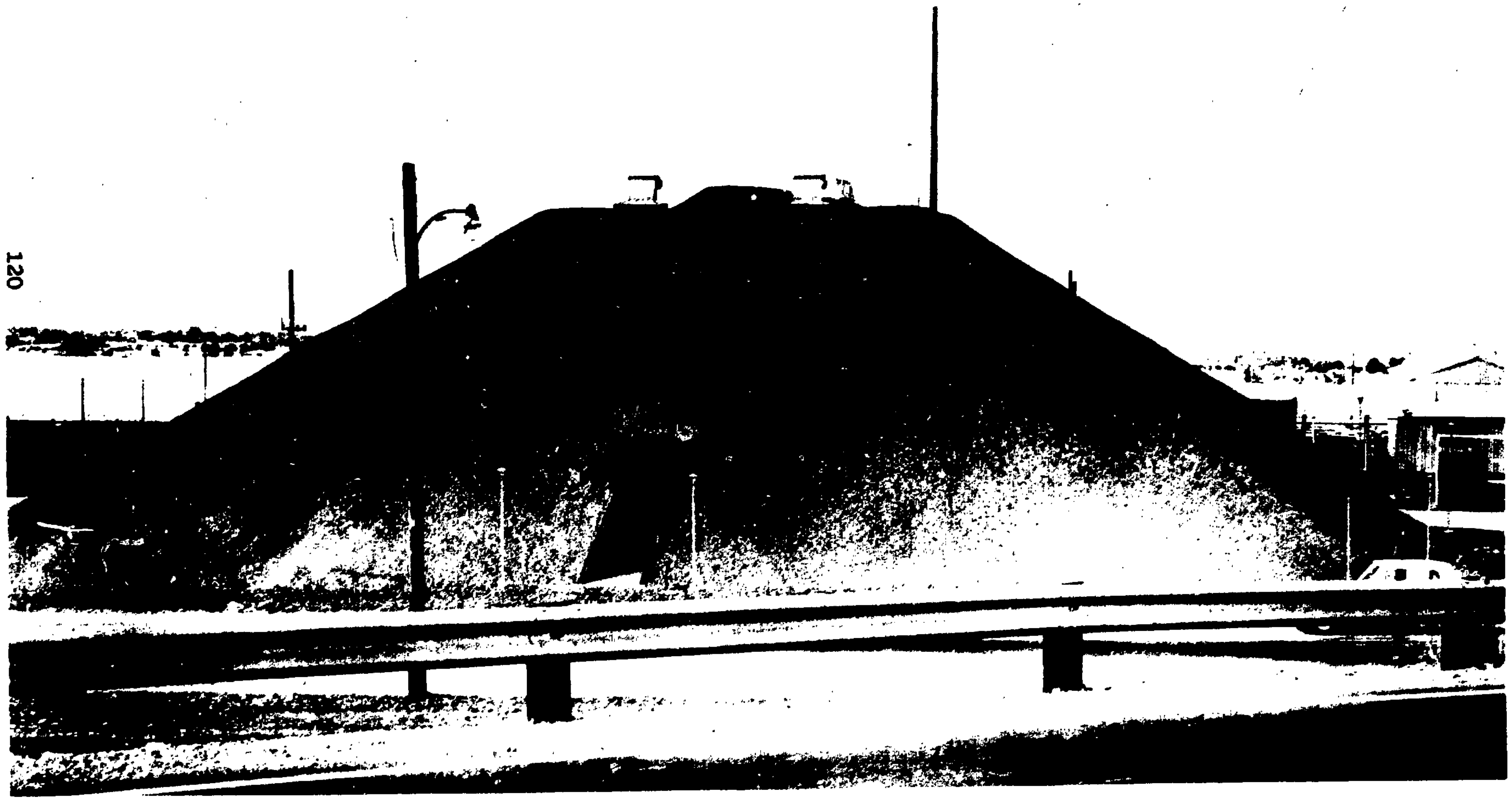


Figure 12



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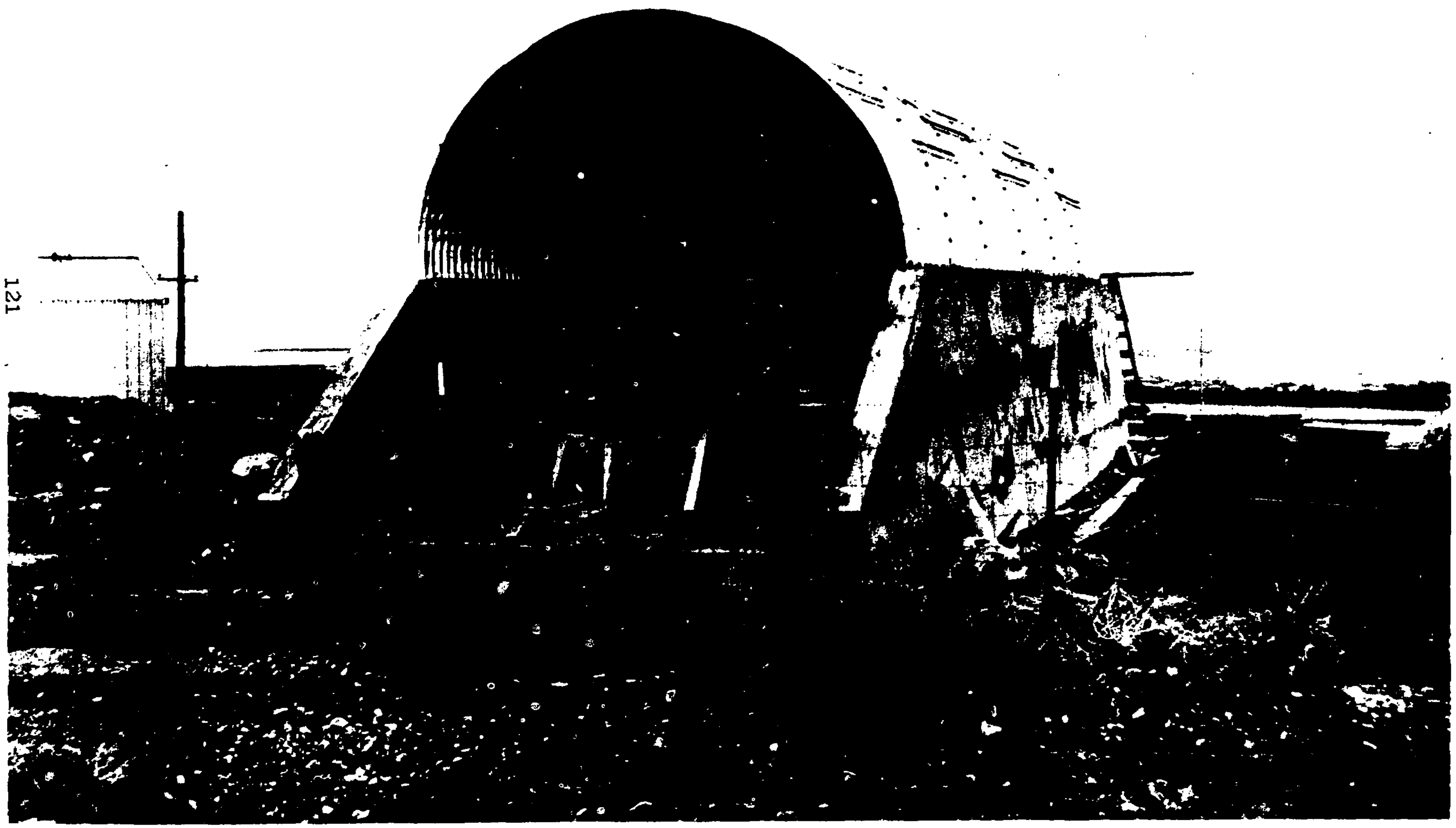


Figure 14

Figure 15

STATE OF RESEARCH ON BARRICADE EFFECTIVENESS
by Victor Davis, URS Corporation

I. INTRODUCTION

During my talk I will attempt to present to you a picture of the state of the art of research in two fields —air blast motion over barricades and missile debris passage over barricades. These are the two subject areas being studied during the course of a contract that URS has with ASESB. The purpose of this contract work is to conduct a literature survey on the two mentioned subject areas.

II AIR BLAST WAVES

The first subject area is that of the passage of an air blast wave, which originates with an HE detonation, over barricade-like obstructions. Only a few detailed studies have been uncovered so far during my search of the literature on barricades in which air blast parameters such as pressure have been measured for blast waves passing over barricades. In addition to these barricade studies, a number of small-scale experimental studies have been performed in shock tubes and with small explosive charges in which blast wave pressures have been measured on rigid surfaces, both flat, and with barricade-like obstructions protruding from the surface.

Using the results of the small-scale studies, it is possible to make at least an educated guess as to what happens to the shock front of the blast wave as it passes by a barricade. It is my intention here first to outline breifly the process of the passage of an air blast wave over a typical barricade-like structure, as suggested by the small-scale studies.

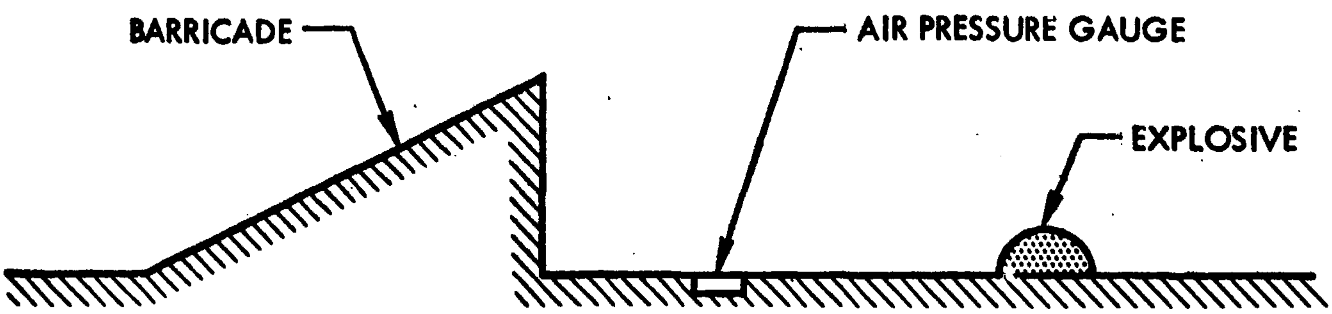
The general physical process which interests us here is that of an HE explosion on the ground which generates an air shock wave, which in turn travels along the ground, up and over a barricade, and continues traveling along the ground after passing the barricade. Consider for the purpose of this simple picture, a compact mass of explosive detonating on the ground, with an outward-moving hemispherical shock front formed by the detonation,

and with a barricade or barricade-like structure located on the ground at some distance away from the HE charge. The picture being considered is shown in Figs. 1 and 2.

The air blast wave thus formed is characterized by a shock front that is a surface where the air pressure rises discontinously from normal atmospheric pressure to a higher pressure. This shock front surface expands radially with time. (See Fig. 3)

At some time after the detonation and before the hemispherical shock reaches the barricade, the air pressure in the region behind the front would, were it measured, be seen to decrease gradually from the air pressure at the front as the point of observation moves in toward the center of the hemisphere. Thus an air pressure gauge, mounted at a point on the ground between the explosive and the barricade, would see a sharp rise in pressure as the shock front passes over the gauge, then a gradual decrease in pressure as the front moves on beyond the gauge. The air pressure vs time seen by the gauge might look something like that shown in Fig. 4. Of course, to completely describe the state of the air at all points within the confines of the shock front, one would have to specify not only the air pressure, but the speed or particle velocity, temperature, density, etc., at all those points.

Next we consider what might happen to the air blast wave when it encounters the barricade during its radial expansion. As the blast wave strikes the face of the barricade, a second shock wave will be formed—called a reflected wave—which travels in the backward direction away from the barricade face. A picture of this combination of shock fronts is given in Fig. 5. The reflected shock front is characterized by a sharp change in pressure above that of the air into which it is moving, and this pressure is greater than the pressure of the original front by a factor of 2 or more, depending on the strength of the original shock incident on the barricade face. Thus this high reflected pressure is the pressure acting on the lower portion of the barricade face. As the original shock front progresses up the barricade face, the reflected shock moves outward as shown in Fig. 6. Our air pressure gauge placed between the barricade and the explosion center would also see the sharp increase in pressure



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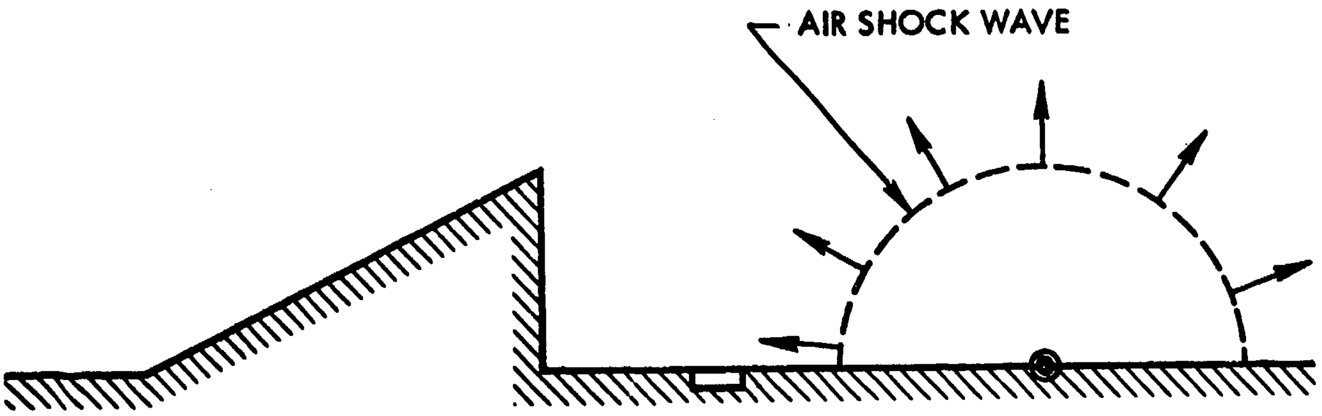

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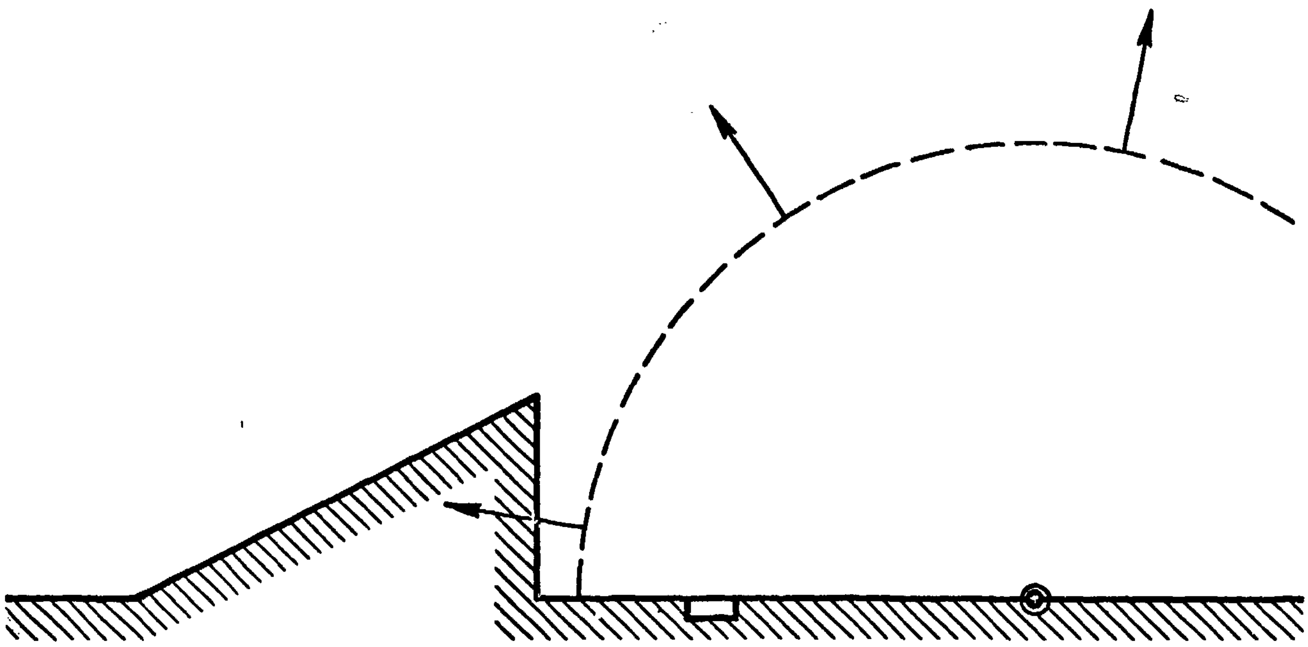

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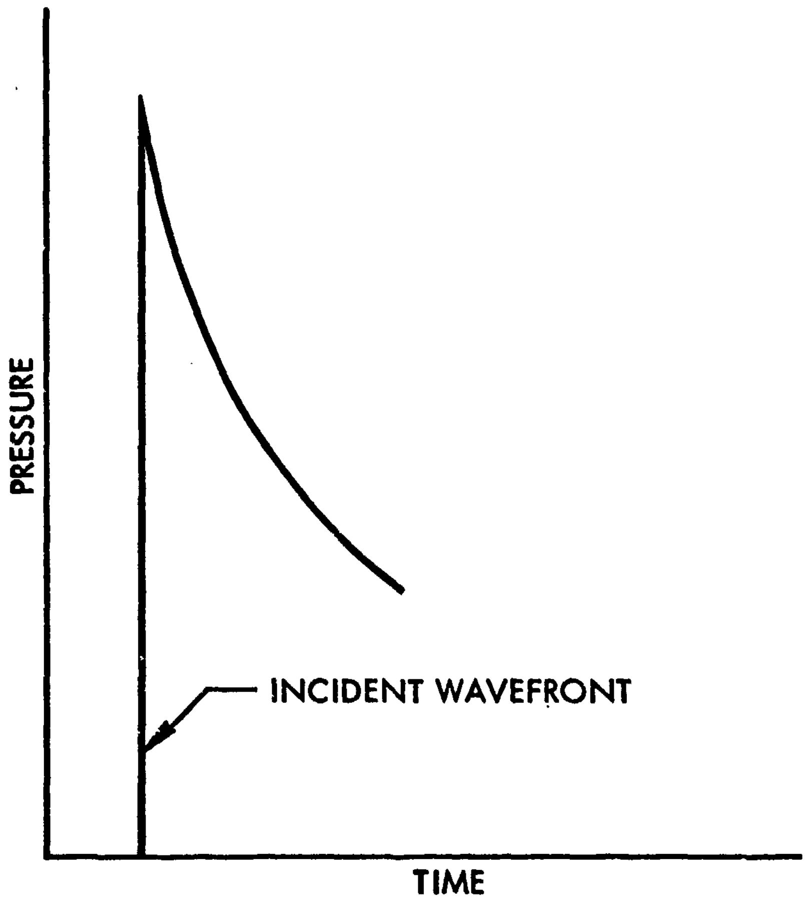

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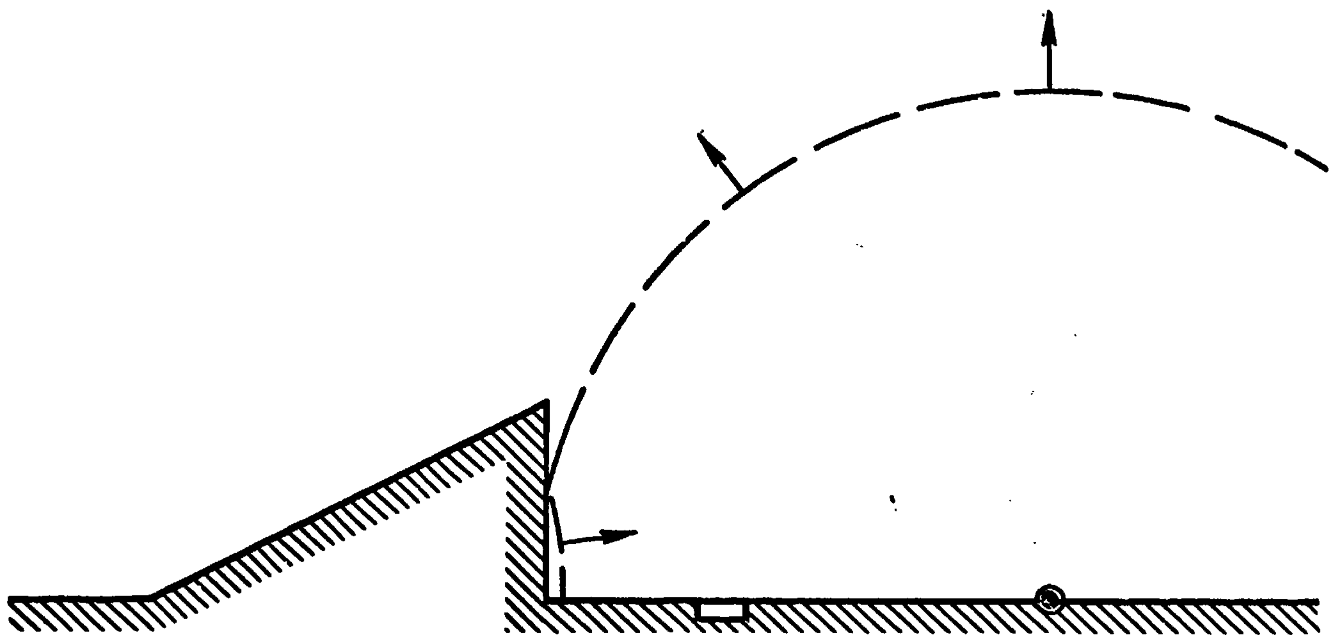


Figure 5.

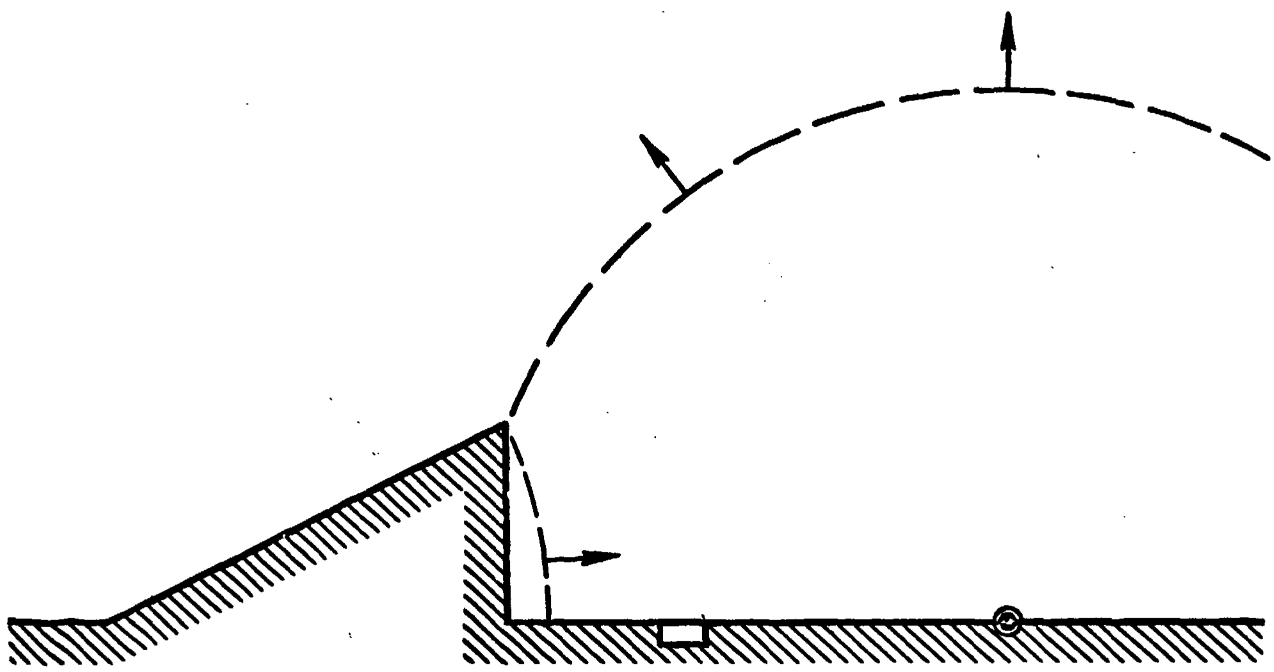


Figure 6.

associated with the reflected shock. The pressure time pattern seen by the gauge might look something like this. (See Fig. 7)

As the shock front reaches the upper tip of the barricade, a process called shock-wave diffraction will take place. In this process, the shock front expands, or spills out over the top and down the back of the barricade. Fig. 8 shows the shock wave picture at a short time after the shock has begun to pass over the barricade. The original shock front pressure is reduced at points near the back surface of the barricade. This has been suggested by the results of several experiments in which diffracted shock pressures were measured, although the exact diffracting surface geometry being discussed here was not used in those experiments.

After passing down the back surface of the barricade, the expanding shock front once again encounters the ground surface. The exact form that the shock front profile takes after the ground is reached depends on the angle between the ground and the back surface of the barricade, and on the shock front pressure; but it might look something like the following. (See Fig. 9).

In Fig 9 we have what is known as Mach Reflection, in which three shock front surfaces are joined at a point. The pressure at the shock front now moving along the ground is increased over its value on the back side of the barricade, due to the reflection process at the ground surface.

A crude picture has been presented to show generally the progress of an air blast wave over a barricade. Exactly how these pressures in the air blast vary with space and time is an important question, in fact, the question of barricade effectiveness as far as air blast is concerned probably hinges upon these pressure variations. Thus, for example, if it cannot be shown that the air blast wave pressure behind a barricade is significantly lower than that pressure which would be there in the absence of the barricade, then the barricade is not effective in reducing blast pressures.

As mentioned earlier, reports on a few experimental tests have been found in our literature survey, in which large explosive charges and full-scale barricades were used. These tests were performed at Soltau, Germany, and Arco, Idaho. I have chosen to discuss briefly a portion of the results of the Soltau tests.

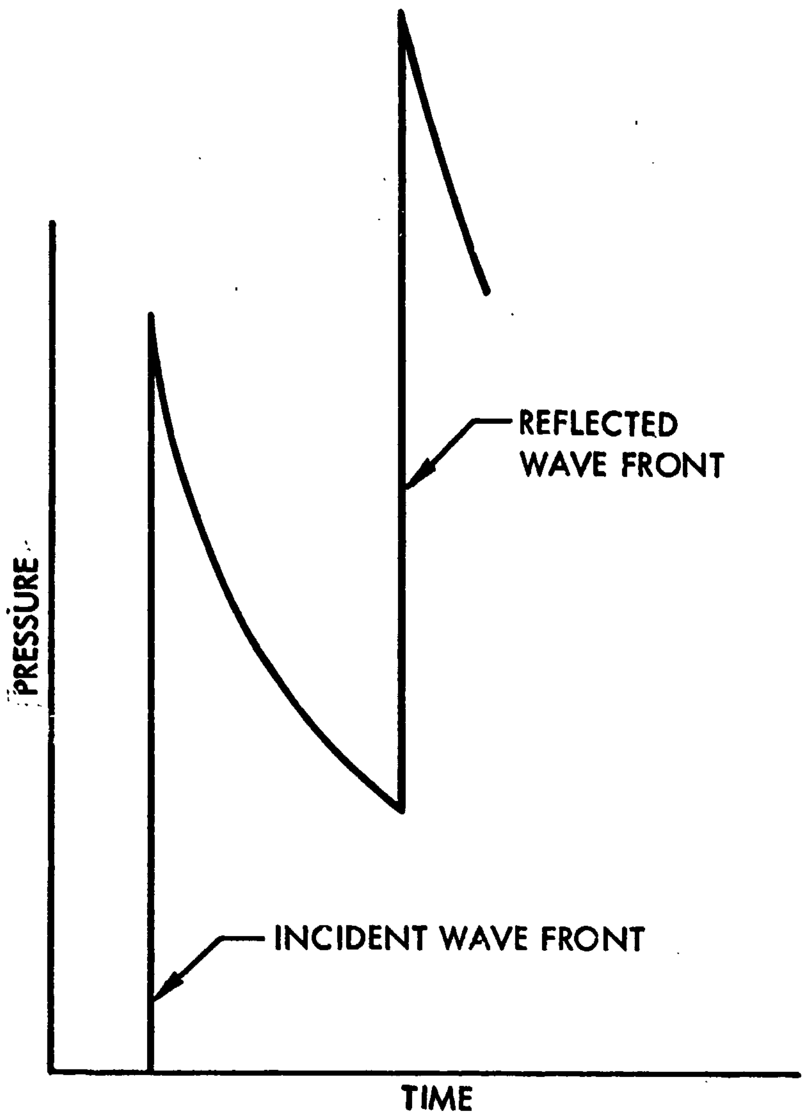
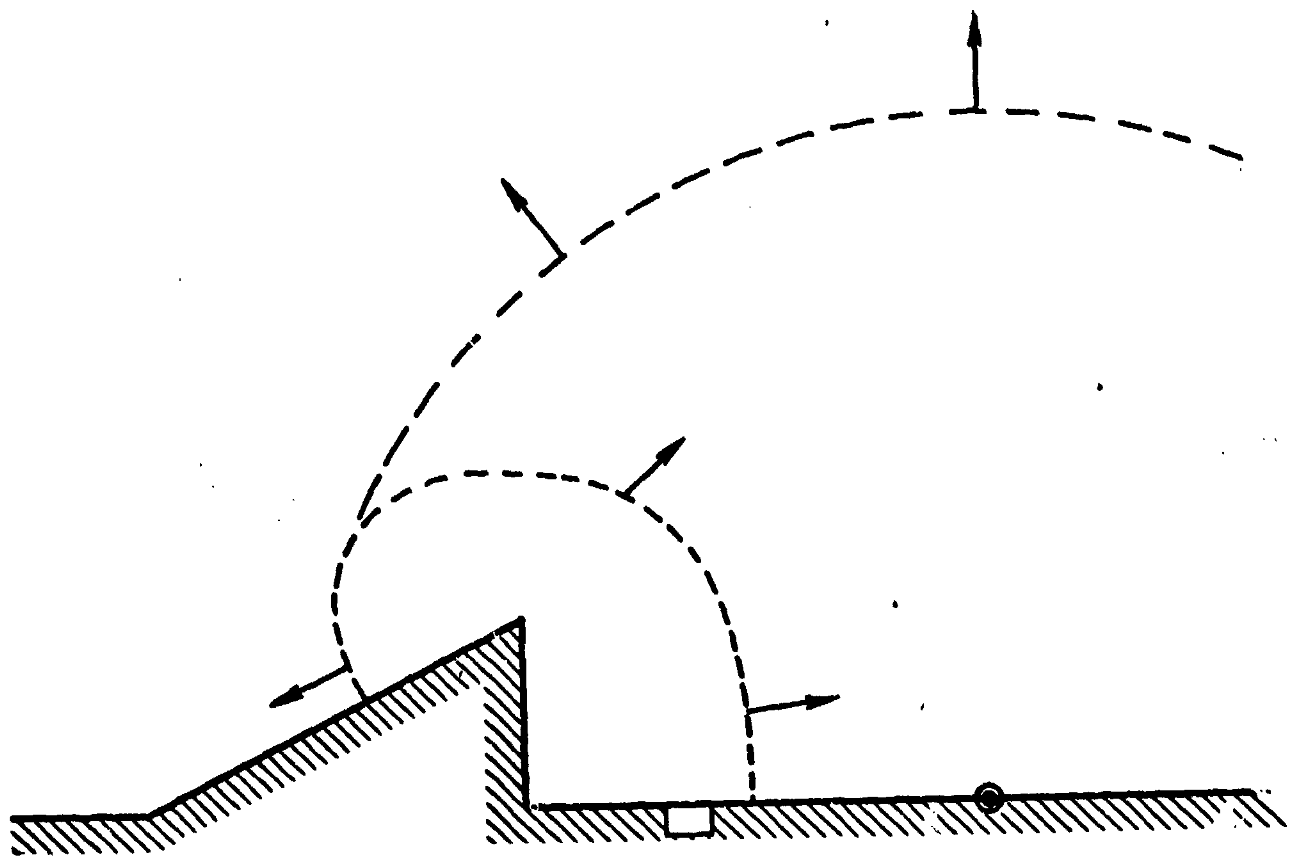


Figure 7.



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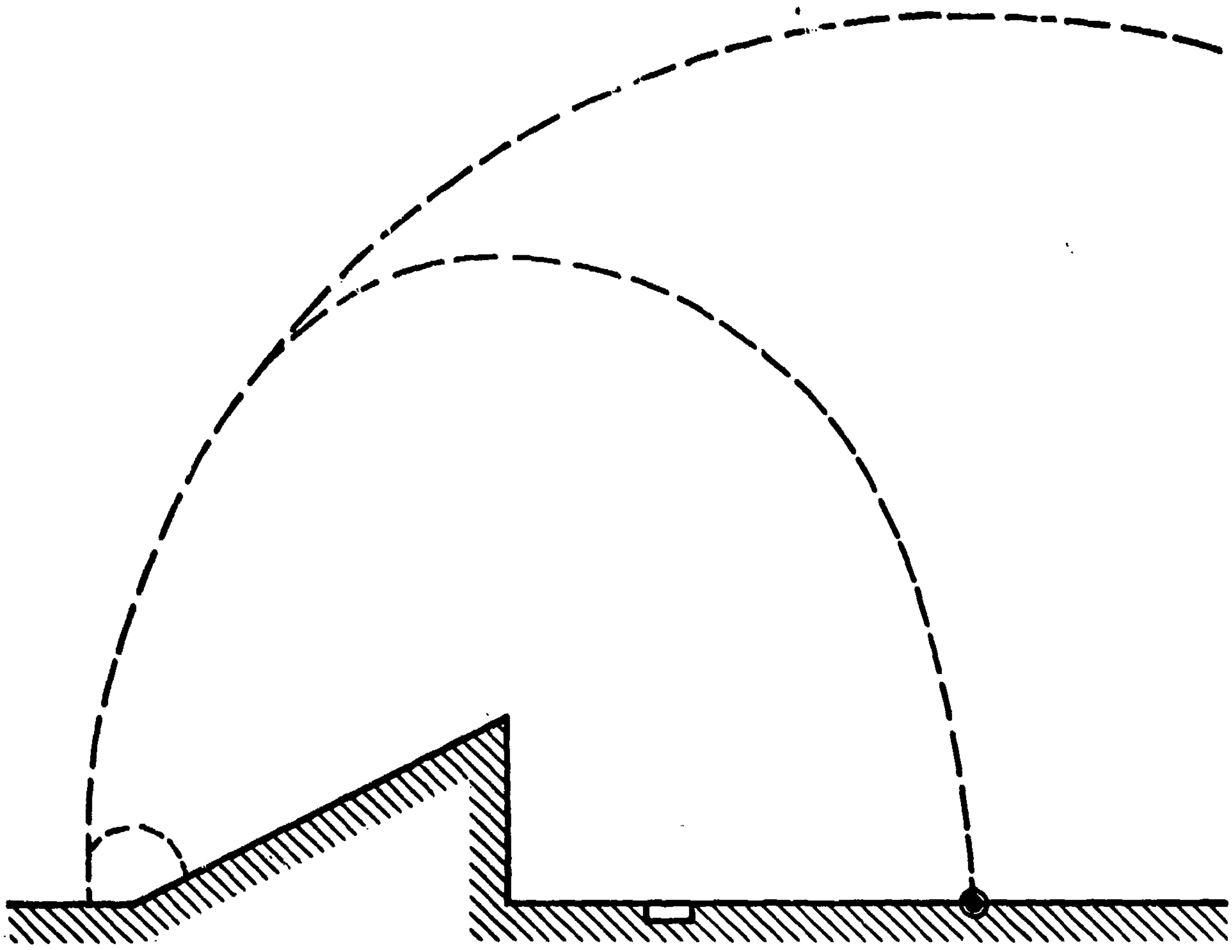


Figure 9.

In the Soltau tests, performed by the British Explosive Storage and Transport Committee, charges of 3.3 tons or 6600 pounds of explosive, in the form of stacked surplus land mines, were detonated both with and without a barricade. The barricade in these tests had a vertical wall on the explosive side and sloping earth on the other side, and the barricade completely surrounded the charge.

Maximum or peak pressure in the air blast wave was measured at various distances from the charge. A comparison of these peak pressures is made for the barricaded and the unbarricaded cases in Fig. 10.

In Fig. 10 I have plotted the Soltau peak-pressure value against distance from the charge as measured in barrier height units. The solid line is the pressure — distance relationship for the open or unbarricaded charge, and the dashed line is for the barricaded case. It is immediately apparent from this plot that the two curves are not greatly different, hence it is to be concluded that the barricade does not seem to be very effective in reducing the peak pressure in a blast wave. There is a small effect to be seen, namely that the peak pressure is reduced in a region adjacent to the charge, and is apprently actually increased at greater distances. The barricaded inhabited building distance for this charge as determined from the American Table of Distances is shown on the plot as a reference. This distance is about at the 1-psi pressure level.

The time integral of overpressure, or the blast impulse, was also computed from the pressure — time data. This parameter is considered to be equally important as the peak pressure as far as determining damage effects is concerned.

Figure 11 is a plot of the blast impulse as experienced at various distances from the explosion. The solid line is for the open charge and the dashed line is the barricaded charge. Note that here the barricade appears to reduce the blast impulse over the entire range of distances, up to 100 or so barrier heights. After the blast wave has progressed some distance beyond the barricade, some of the available small-scale experimental studies indicate that the blast wave near the ground tends to reform to the state that it would have been in had the barricade not been there. These studies indicate that this distance where the blast wave reforms may be from 5 to 25 barricade heights past the barricade.

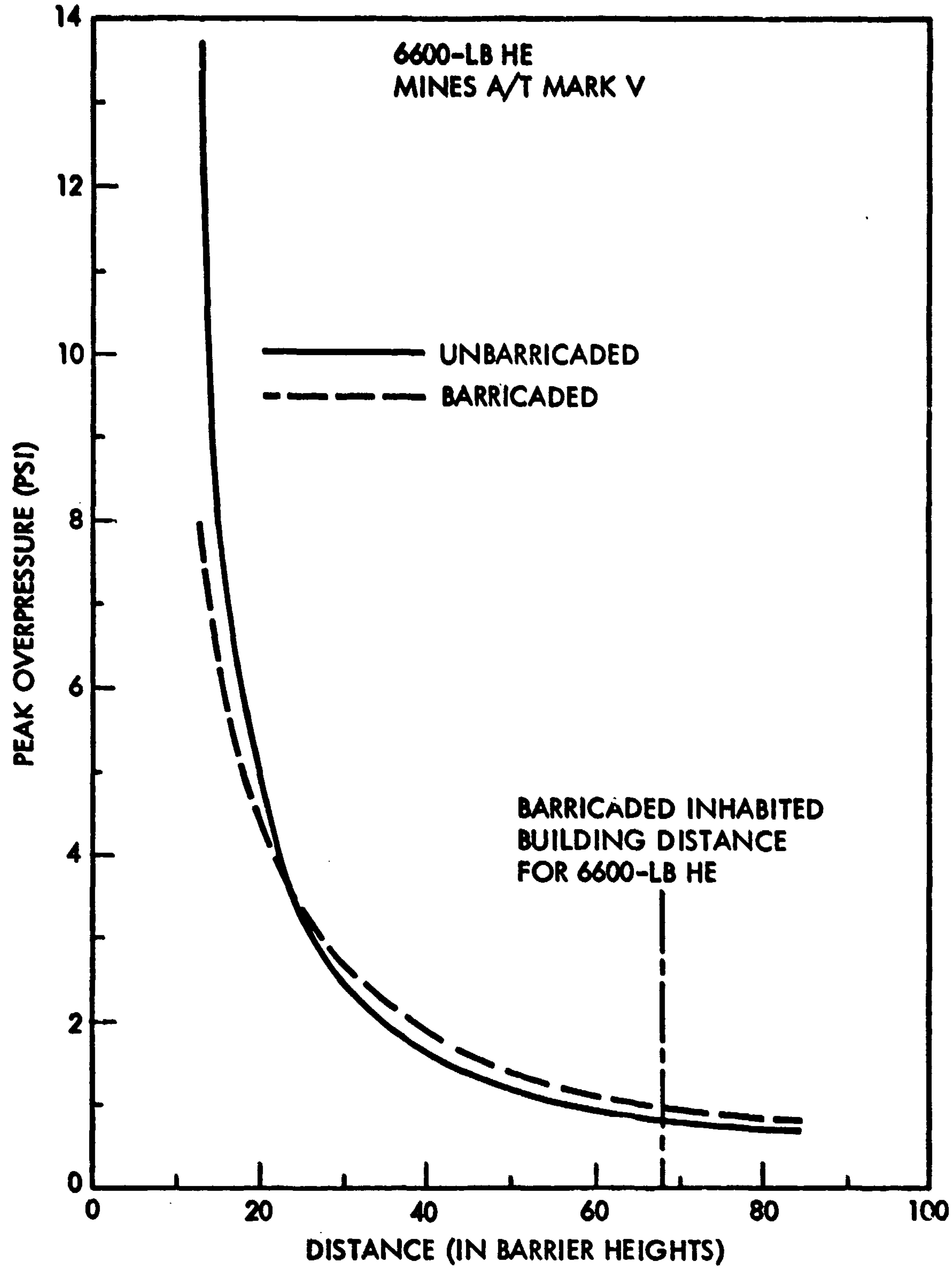

6600-LB HE
MINES A/T MARK V
UNBARRICADED
BARRICADED
BARRICADED INHABITED
BUILDING DISTANCE
FOR 6600-LB HE
PEAK OVERPRESSURE (PSI)
DISTANCE (IN BARRIER HEIGHTS)
0
2
4
6
8
10
12
14
20
40
60
80
100

Figure 10.

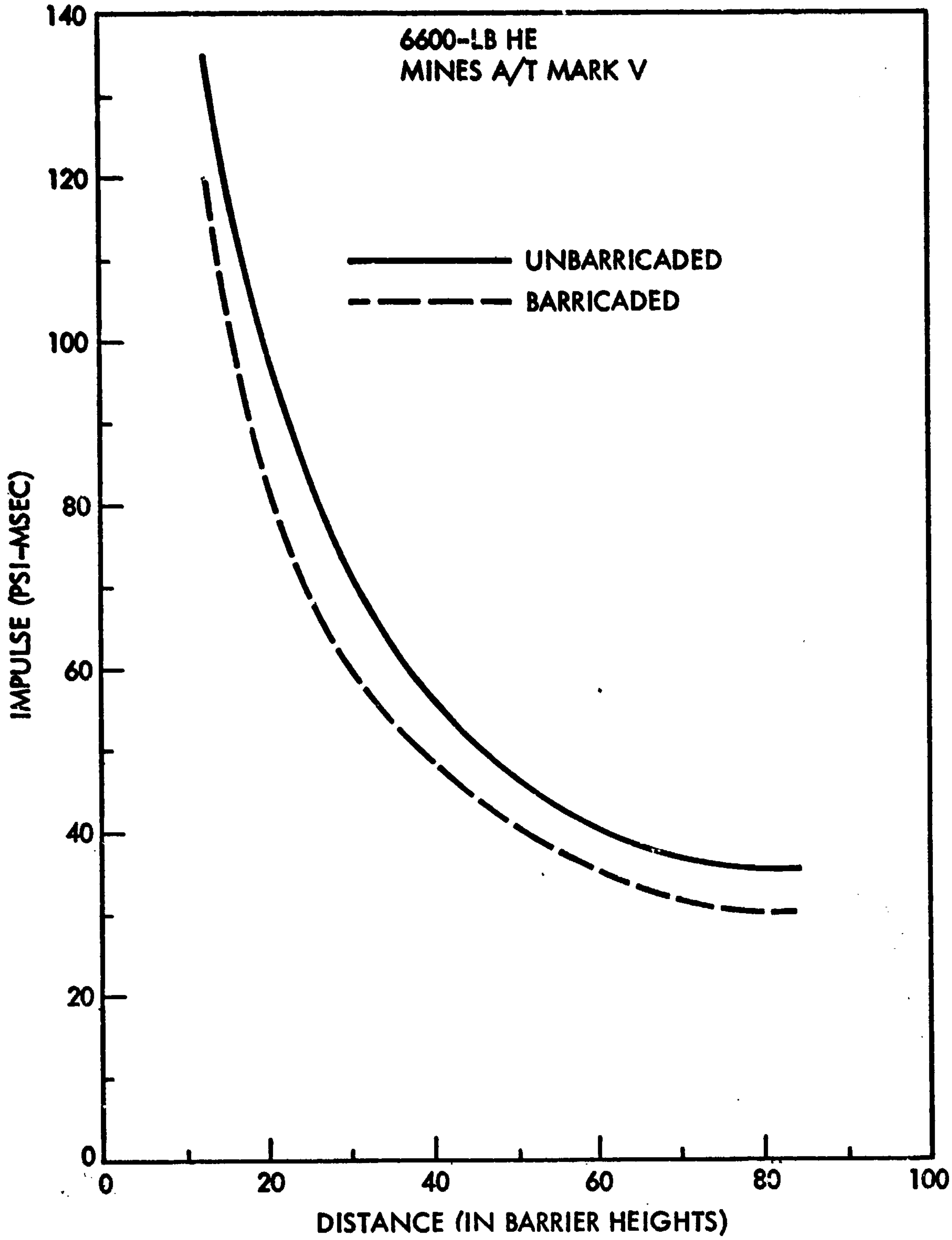

6600-LB HE
MINES A/T MARK V
UNBARRICADED
BARRICADED
IMPULSE (PSI-MSEC)
DISTANCE (IN BARRIER HEIGHTS)
0
20
40
60
80
100
120
140
0
20
40
60
80
100

Figure 11.

During the course of our literature survey we expect to come up with recommendations for research programs which would be aimed at defining the air blast field around and beyond the barricade. Such information would be useful in evaluating the effectiveness of barricades currently in use in reducing air blast damage, and might show the way to design an effective barricade.

III. FRAGMENTATION

The second problem area of interest here is that of the effectiveness of barricade structures in stopping flying fragments or missile debris created by an HE explosion. With the exception of the fine work of Mr. Filler on accidental explosions, no detailed experimental or theoretical work has been uncovered in our literature survey which treats the problem of barricade effects on flying fragment distribution. In view of this lack of information, about all that can be done here is to outline the problem, and suggest important parameters which could be studied. These parameters are suggested by several pieces of experimental and theoretical work on fragmentation problems in general, which were not directed toward solving the barricade problem specifically.

As in the discussion of air blast propagation over a barricade, I will try to formulate the problem of fragmentation near a barricade by means of a series of simple drawings which point out some of the phenomena associated with the problem.

We start out with a simplified vision of a barricade, a mass of explosive, and a structure around the explosive (See Fig. 12). After detonation, the air will be filled with fragments from the structure, any casings around the explosive, and material from the crater produced in the ground surface. A few pieces of theoretical and experimental work have been done to demonstrate and explain the pattern of fragmentation created in this way. In particular theory has been worked out to predict the breakup pattern of a simple structure, such as the one shown here, and experiments and theory are available for determining the fragmentation pattern of bomb casings. However, as stated, this work does not bear directly on the problem of barricade effects on the fragment distribution.

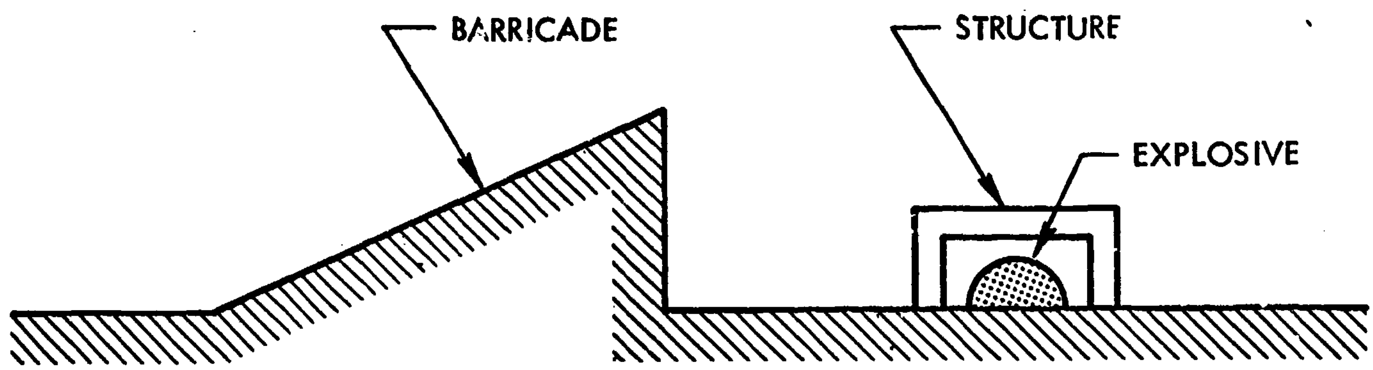


Figure 12.

To continue our simplified problem discussion, let us try to gain some notion of what the barricade might do to the fragment distribution (See Fig. 13). This figure simply indicates that the barricade will certainly interfere with a portion of the field of flying fragments. At least for as long as the barricade remains standing and does not disintegrate, then it is obvious that that portion of the fragment field near the ground will be eliminated, and that those missiles whose trajectories intersect the barricade will not produce effects on structures or people in some area behind the barricade. However, it may be that <u>some</u> missiles will still strike the ground behind the barricade, namely those whose trajectories do not intersect the barricade, but which are low-velocity medium angle, or high velocity-nearly vertical angle missiles.

In Fig. 14 we have drawn in several possible trajectories of fragments. One intersects the barricade and stops, one passes over it and over the ground immediately behind the barricade, striking the ground some distance from the back of the barricade, and one strikes near the back of the barricade. Thus in this case, the barricade can be said to reduce the missile hazard in the region directly behind the barricade; but the question remains, is that region to be considered safe as a result of the barricade effect? To answer such a question, a research program is required in which missile distributions with and without barricades are either measured or theoretically predicted.

Now let us discuss the way in which missiles and fragment pattern problems are normally treated, that is, how the missile field is described in such studies. A picture of this research field may indicate an approach to solving the barricade effectiveness problem for fragments.

Ideally, from a physics problem standpoint, one would like to be able to specify the fragment field distribution, in terms of missile weight or missile number density in space, and the missile velocity, as functions of position in space and time. The usual treatment of missile debris problems is restricted to describing the spatial distribution of the fragments at a late time, that is, after the fragments have completed their trajectories and are at rest on the ground. A typical way of presenting data on ground distribution is shown in Fig. 15. Here the parameter of missile density is plotted against ground range.

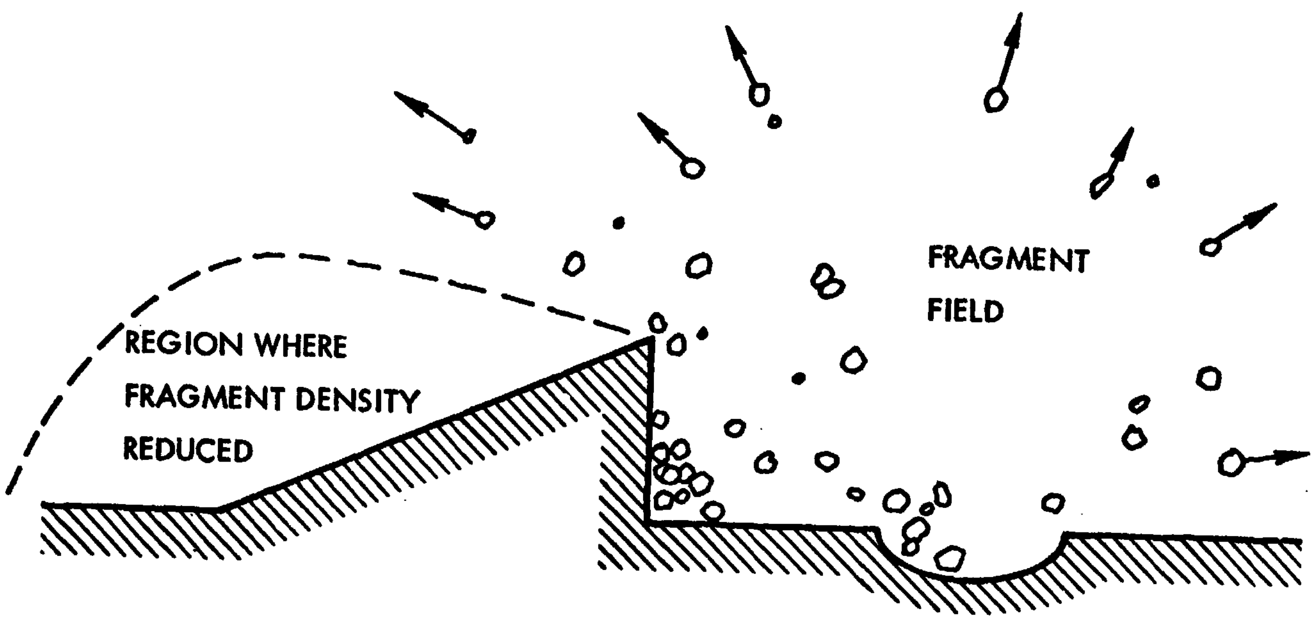
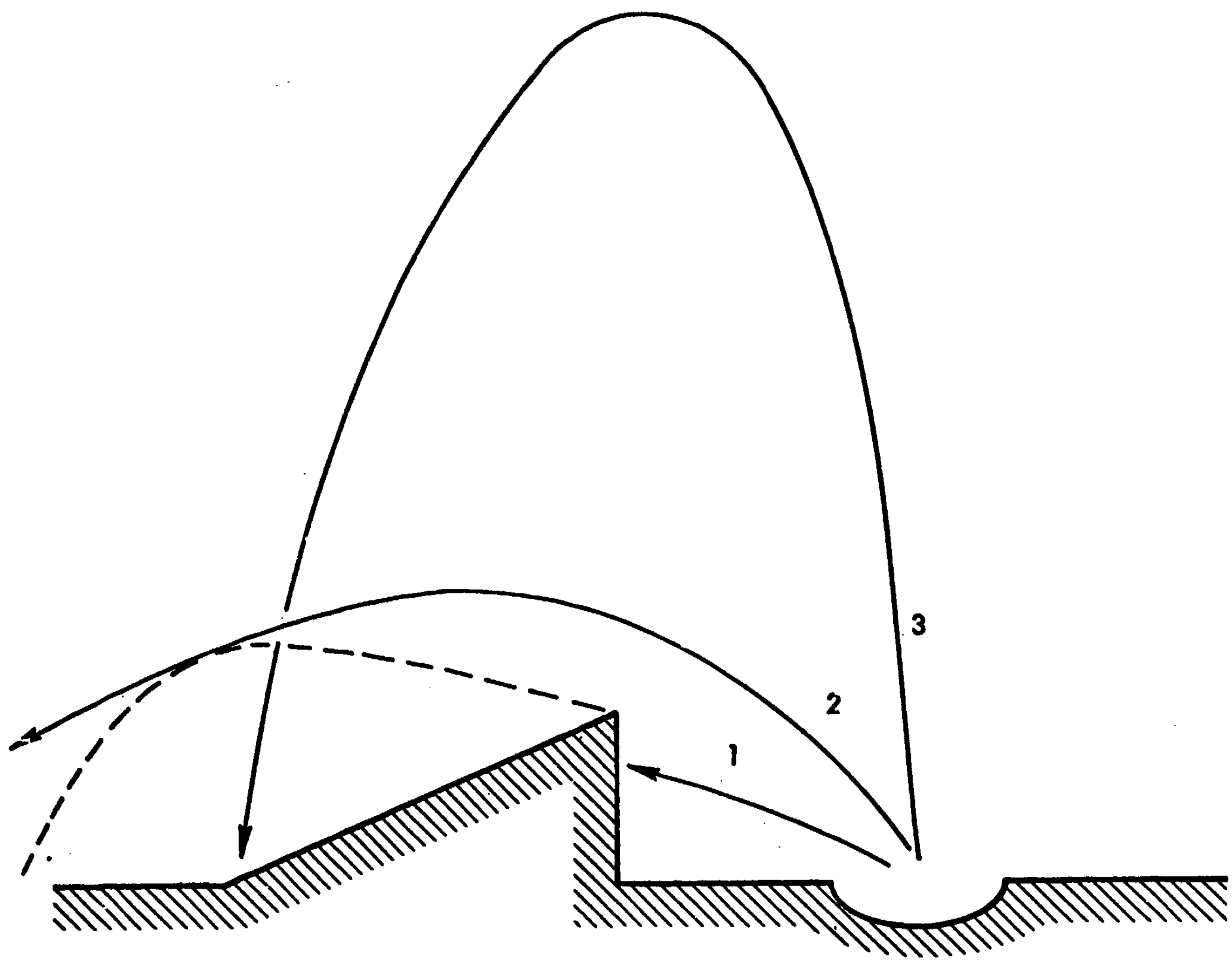


Figure 13.



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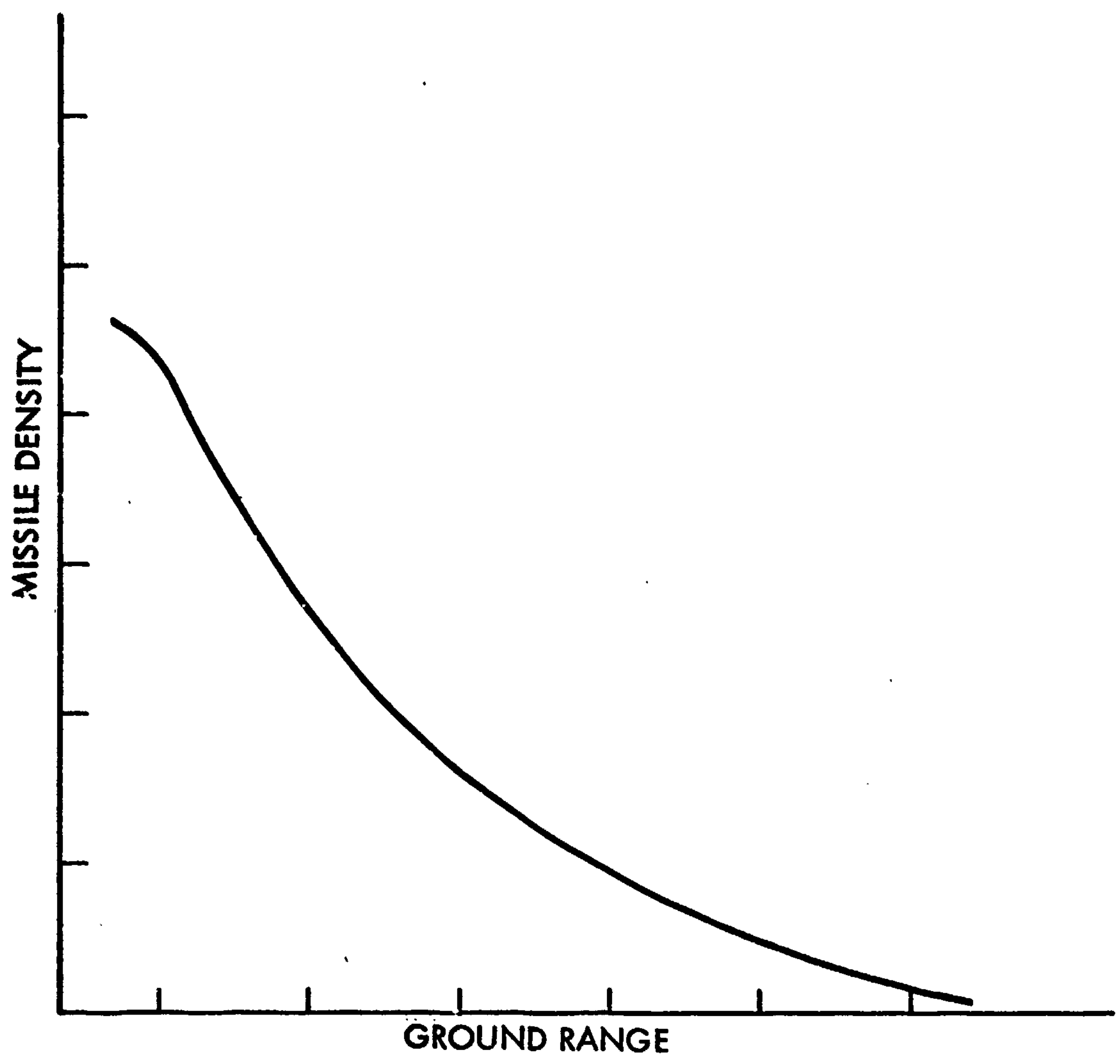

Figure 15.

The missile density can be given in fragment weight per unit area or it is sometimes given as number of missiles regardless of size per unit area. Occasionally the inverse of density, or area per unit missile weight is given. One such plot would be given for each particular intial explosive weight and initial containing-structure geometry, as clearly the resultant missile density depends on these conditions. Thus the parameters which one might study in a research program to determine missile distribution would be:

- explosive weight
- containing-structure geometry
- missile density
- ground range

In some studies, only the maximum missile distance is plotted as a function of explosive weight. These plots give an indication as to the absolute safe distance from an explosion.

One can now imagine what could be studied in a program to determine the effectiveness of barricades. The study could be directed toward generating a pair of plots of debris density versus ground range for each explosion weight and geometry; one plot for the distribution of the debris without a barricade in place, and one for the distribution with a barricade.

In conclusion, it may be said that very little has been done in the way of scientific studies of the effectiveness of barricades in reducing hazard due to air blast and flying fragments resulting from detonations of stored HE. However, other studies in the fields of air blast and fragmentation offer an indication of which are the important parameters to study in a research program designed to evaluate the effectiveness of barricades. Such basic studies should be performed to provide background for effective barricade design.

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M. T. STUCKEY, THIOKOL CHEMICAL CORP: I sat through a couple of wars on loading plants where high explosives were used. I've seen melt pour buildings go up and leave the other buildings there and I hear more damn theories about what barricades will and won't do. If I'm out on one of those lines I want a barricade. One of the fellows up there, I don't remember which one it was, said that the barricade was torn all to hell; the next guy says it went over and formed on the other side like nothing ever overcame it and it starts out in Bangor, Maine and goes around the world continuously; the third guy had some theories also. I think our big problem with barricades really is the fact that a lot of people are using them wrong and for the wrong purposes. Personally, if I had a barricade up and it completely disappeared, I know that there's only a certain amount of energy that comes out of an explosion whether its 5 pounds or 500,000 pounds, and if part of that is eaten up in tearing up the barricade, its going to do a hell of a lot of good as far as the buildings down line and the people down line are concerned. I don't think from what I heard, all three of the speakers I heard all have a different theory about barricades. My question really is, am I supposed to knock down my barricades and replace them with theories?

PERKINS: That's what we were trying to find out: "what your question was Max." We thought you were adding yourself to the panel. Do any of you wish to address yourselves to his remarks?

DAVIS: I'd like to make one remark. My talk simply said we don't know what to tell you to do with your barricade but it might be possible to find out with a little research program or two.

FILLER: What I was trying to say is just that any engineer who wants to do a job has to know what he has to design for. I don't think that that situation exists today with respect to barricades. You may have the best complete confidence in using barricades in the sense of thinking that its going to do something good for you. All I'm saying is - in an objective engineering sense in terms that you use numbers to design for a designers structure - you just don't have that situation today with respect to barricades. You don't know how to build them in terms of quantitative loads and that's the way an engineer should function if he has data available to him. The other point that I was making is that there is data around which could be applied which isn't being used today for the design of barricades.

STUCKEY: But there hasn't been anything better come along, that's what I'm saying.

FILLER: No one has worked at it. There are plenty of data around that could be used but haven't been used.

W. G. HAYDEN, OLIN MATHIESON CHEMICAL CORP: I'd like to direct my question to Mr. Gott. I believe Mr. Gott indicated that there seemed to be a definite trend in the construction of buildings now that will give

heavy overhead protection from flying missiles or fragments or overpressure, whatever you want to call it. I'd like to ask Mr. Gott who subscribes to this philosophy in Hercules and I would like to ask the Corps of Engineers whether or not they subscribe to this philosophy of building buildings to retain the overpressure inside the building?

GOTT: I hope that I concluded by saying in my summary that based on our actual experience in industry we cannot hope to contain an incident of any order of magnitude. Regardless of what we do in protective design construction, if the incident occurs inside that building we will lose the barricade. But experiences in the plant show that there is a great deal to be achieved from protecting those target buildings. And the more protection we can give them, up to and including earth covered structures, the least damage we suffer in structural damage and in the probability of propagation. I can speak for Hercules, it is Hercules trend to go that way in all new construction where practical and economical, and in looking at other records, some of the other plants are doing this too.

CAPT. SCHWEER, NAD HAWTHORNE, NEV.: I have two questions and I'd like to direct them to any of the three gentlemen who would like to answer them. The first question concerns the theory of the so-called zone of immunity. I've heard of this and I wonder if there is any truth to it. And the second question, I wonder if any studies have been made about having explosions on the other side of the barricades. For instance, directing it up into the air and I'm concerned only with blast damage.

PERKINS: We are making studies on that subject, not only as to explosions on the other side of barriers and barricades almost constantly with amounts varying from small amounts and relatively thin structural barriers to large quantities up to 250,000 pounds or so and massive earth mounds between. If this is what you mean by explosions on opposite sides of the barricade.

(Capt. Schweer spoke but microphone was not turned on)

PERKINS: You're speaking of the contour of the barricade with respect to the blast?

SCHWEER: That is correct.

PERKINS: This is one of the questions which Mr. Davis indicated and Mr. Filler indicated needs further study. Would either of you like to address yourself to that.

DAVIS: You remember on that plot I showed you blast pressure vs distance, for the barricaded case the pressure apparently went up, not very much, but it went up, the gages showed the pressure went up anyway, at large distances away from the barricade. In the paper where this thing was written up they made the suggestion that the air blast wave had been sort of propagated straight up in the air due to the face of the barricade

and that once it was up in the air the whole situation acted more like a detonation from a certain height of burst rather than on the ground and they thought they could explain the increase in pressure by that. That's just an indication of the only thing I came across where they concerned themselves with the contour of a barricade and it isn't very satisfactory.

(Someone asked about zone of immunity - microphone not turned on)

PERKINS: What do you mean by "zone of immunity?" I'm not familiar with this phrase. We have quantity-distance tables and we always say they're not safety distances, they're distances indicating relative risk. So you'll have to define the term a little more.

(Comment - microphone not turned on again)

PERKINS: A man in the audience wishes to respond to this question.

KEN KAPLAN, URS CORPORATION: Just in response to that point being made about the meteor explosion, recently, last year there was a similar case carried out with high explosives in Canada where 50 tons of TNT were detonated in the middle of a forest. It was a pretty big forest. For something over 100 feet beyond the 50-ton explosive, 150 feet I think in radius, there wasn't anything left standing, everything was down. There was a crater in the immediate vicinity of the explosion. In general the damage increased from the center of the explosion and was greatest near the center of the explosion.

FILLER: I don't know if this directly bears on the question. It might be related. In general, one might expect from a shock wave effects point of view, some regions where the pressures would be lower on the back side of a barricade. Its just that its not a well defined region right now and its certainly not true that pressure is not going to be elevated to some extent. The pressure is going to be variable as a function of time and depending on where you might be. There is going to be blast pressure in general behind the barricade.

PERKINS: Its true and quite in evidence from many of the accidental explosions we have observed that there are anomalies in the damage done and casualties produced due to irregularities as prescribed in the blast pressure. I would hesitate very much, however, on the basis of the knowledge I know any of the people in this room to possess to ask them where is the "zone of immunity" for me to be in the case of any given explosion.

D. G. ROBINSON, TOOELE ARMY DEPOT: Do you have a standard drawing or approved method of securing a barricade in an operating building such as bolting or welding them to a wall?

PERKINS: If I might suggest, this might better be taken up in the specialist session on protective construction tomorrow. Its something that can't be answered briefly here from the floor.

A. B. WENZEL, GENERAL MOTORS CORP: I'd like to direct this question to Mr. Davis. You showed us a graph which compared pressure as a function of distance for barricaded and unbarricaded structures. The pressures were measured with some sort of gages that you had somewhere along the ground or in the vicinity of the structure. I'd like to make the following point. That for any explosive charge in direct contact with the ground, the detonation wave front will not be as simple as the one you showed in your talk because an explosive charge will generate an incident wave and also because it is in direct contact with the ground it will be a reflective wave coming off the ground. As the wave channels thru space you will have the reflective wave cause the refraction wave and the refraction wave is going to interfere with your incident wave and any transducer or gage placed in its path is going to give data that is going to be confused. I don't know how you interpret the data to show such smooth graphs as the one that you showed. Would you care to comment please?

DAVIS: I'm just trying to make a guess as to what is going on. I have admittedly small knowledge of air pressure gages and air blast waves. I would suspect that an air gage placed where it was would be a double peak, maybe there would be lots of little hash and stuff in the actual case but the general picture might show a double peak due to the incident and the reflected waves. If you have a better idea of how it works come on out with it.

WENZEL: All I'm really saying is the problem is a complicated one and it's extremely difficult especially for the 6,000 pound charges. The graph that you showed was for 6,000 pounds. These were actually as I interpret from your discussion, land mines stacked one on top of the other. I don't know how you detonated this thing but I assume somewhere in the pile you detonated this thing and these things in turn propagated from land mine to land mine and every time you go thru a free surface, there would be refraction waves coming off each surface. I can't see how you could come up with such smooth curves as the ones you showed with any gage in the market today.

FILLER: These are two separate things. I believe Mr. Davis was talking first about just generalized ideas about what the shock wave does. In the Soltau tests, which I'm also familiar with, the graphs that he showed are in a very low pressure region at great distances and you could put a pile of almost anything just so long as the material generally propagated thru the pile and at that distance it would look like a homogeneous charge went off. So the detail of what went on in terms of fragments and such would be pretty much not too relevant. Thus it is generally appropriate to use this kind of data because the inhabited building distance is out in the low pressure region and the detail of what happens initially is generally not too important as compared with the total mass of the explosives that went. As far as your comment about what happens locally, its true you lose energy in the ground but you can sort of take account of that. Its about a 10 or 20% loss of energy and then forget about it because the blast wave at substantial distance evens out and you can look at the whole thing as if you

had an ideal charge going off with a certain percentage loss of energy but the blast wave will still be quite smooth once you get out into the lower pressure region.

H. METCALF, OFFICE, SECRETARY OF DEFENSE: I haven't been directly involved with high explosives for some ten years but it seems to me that about ten years ago there was no-one who would hold that a barricade was particularly effective in reducing blast pressure. In the intervening ten years I've been involved more-or-less with nuclear weapons sort of thing and from all of the tests that I've seen from the Pacific, from Albuquerque, from Canada, from Aberdeen, everywhere, I've still seen nothing that would give me any indication that a barricade would be effective in reducing a blast pressure for anything more than a small shadow of distance beyond a barricade. In the face of what appears to me to be substantial evidence I wonder why you would recommend that we make additional research effort to determine that if there is a great deal to be gained from research in that direction?

PERKINS: May I take the liberty of responding to that question and also summarizing briefly what we have said here. I hope I can. We have only suggested that there are a great many unanswered questions with respect to barricades and barricading and that the barricade as originally conceived is evidently not capable of doing everything that the original designers hoped and confidently expected it would. We feel we have clear indication for instance that barricades markedly reduce the risk of propagation between adjacent stores of explosives and similar situations such as that. We have not either said that in terms of absolute values that any distance prescribed in current regulations is inadequate. We have only said the parameters involved in the use of barricades are not sufficiently understood to justify the present costly, irregular, and uncertain approach to some of the specific problems that are proposed. In short no one in this group has yet said barricades are "no damn good" officially.

FILLER: I'd like to add that the research program that needs to be done is to define just that. Let's find out where they do do some good. We know very definitely they are being used for purposes for which they were no damn good and too many people realize this who know something about blast.

EXPLOSIVE ACCIDENT/INCIDENT INFORMATION REPORT SYSTEMS BRIEFING

LCDR J. B. Biron, USN
NWL Dahlgren, Va.

During the next 20 minutes I hope to familiarize you with the explosives accident/incident reporting systems of the Army, Navy, and Air Force by giving you a little history and philosophy behind their inceptions as well as some of the problems we are facing.

The Army made a relatively early start in the explosive safety reporting field back in 1918. Of course, all of the effort was done by hand and was very basic. During WW II, the Ordnance Corps began to keep detailed records, still by hand. When the Army Materiel Command came into existence in 1962 it inherited the explosive safety function. It was during this period that the complex explosive safety program and its associated reporting system developed.

Since 1 July 1961 the Army has adopted automatic data processing as a means of recording accidents. Each major command reports its experience quarterly directly to the Deputy Chief of Staff for Personnel (DCSPER). Analysis of this data is available directly to the Chief of Staff, US Army.

The Army Materiel Command has used this data, as it relates to AMC materiel, for further computerized studies and as a basis for recommended action for the prevention of accidents.

In FY 67 AMC had over 4 million dollars loss and 26 fatalities in explosive accidents. (Figure 1)

The Navy is a newcomer in centralized reporting of explosive accidents/incidents. Prior to 1963 each weapon system project officer in the Bureau of Ordnance maintained accident files on his weapon system, but they were by no means complete. Since 1963, explosive accident/incident information has been accumulated in a computerized fashion by the Missile Safety Staff at the Naval Weapons Laboratory, Dahlgren, Virginia for the Naval Ordnance Systems Command Safety Division. Presently the Navy allots only $10K per year to process its explosive mishaps. (This includes Marine Corps mishaps but does not include any investigation which is funded separately.) Fig. 2

When the Air Force became a separate service in 1947 explosive safety functions fell to the AF Director of Materiel. In 1956 the accident/incident reporting system was inaugurated. In 1960 the management responsibility was transferred from the AF Logistics Command to the Deputy IG for Inspection and Safety, Director of Aerospace Safety, Norton AFB, Calif. (Figure 3) At the present time the Air Force is gearing up for a very detailed computer system called Aerospace Safety Data System to help forecast safety problems. Today the Air Force expends about 14 man-hours processing each explosive mishap.

You will notice that I used the phrase "explosive mishap" several times. This was carefully chosen to avoid any wrong definitions.

Now, before we get into the subject of definitions, let's take a look at a WWII film clip taken aboard an aircraft carrier when a bomb broke loose during an arrested landing. (short film shown)

Incidentally, the photographer was killed. As far as the Navy is concerned, there is no question about it. That is an explosive accident. Unfortunately, not all "unplanned explosive events" are so clearly defined. As we get into the various safety documents of each service, different questions arise, such as: (Figures 4)

All or some of these factors affect each Service's determination of whether the mishap was an: (Figure 5)

Now let's take a look at a similar happening about 25 years later aboard, coincidentally, the same aircraft carrier. As you can see from the explosive safety standpoint, nothing happened, so the Navy could call this one an explosive incident. (Figures 6, 7, 8, 9, 10)

The Army says: an accident report required because the cost of the bomb is over $100 - Figure 11.

The Air Force says: an explosive incident (Figure 12).

Let me give you another one, this time without pictures. One of our planes, landing at Da Nang had a 500 pound bomb break loose similar to the previous examples. But this time it skidded off the runway and exploded. It moved a lot of dirt around, put a hole where they didn't particularly want one, but no one was hurt and there was no material damage. How would you call that one?

The Army says: Accident report required. Again because the cost of the lost ordnance is over $100. (Figure 13)

The Air Force says: An explosive accident (Figure 14).

The Navy says: An explosive accident (Figure 15).

Let us now suppose two or three men received serious injuries. Now the Army would call this an accident and the others would agree. To carry this corollary one step further, we will swap that 500 pound bomb for a SIDEWINDER or BULLPUP missile and have it ignite when the plane sets down hard but the warhead doesn't detonate. No damage is done.

The Army says: Hazardous condition, reported as a malfunction (Fig. 16)

The Air Force says: A missile accident (Figure 17).

The Navy says: An explosive accident (Figure 18).

Why do we have these differences? Basically its because each Service saw its needs and attempted to fulfill its needs as it thought was best. The needs of the individual Services were not and are still not always similar and compatible. Believe me when I say the landing strips in Vietnam, the Air Force Bases here in the States and aircraft carriers are three separate and distinct problems. The needs within an individual Service may not always be completely compatible with each other. Let me show you a safety problem the Navy is presently coping with.

We have found safety, in the Navy, to be a many headed beast. Let us assume the whole area of safety to be represented by this (Figure 19). We might then represent ship safety as covering this much of the whole area (Figure 20). Industrial safety as this much (Figure 21). Note the overlap of effort. Flight safety (Figure 21). Traffic safety (Figure 22). Ground safety (Figure 23). Submarine or underwater safety (Figure 24). As you can see this continues to build up in complexity (Figure 25). Weapon safety (Figure 26). And explosives safety (Figure 27). There are more areas such as nuclear safety, chemical and biological safety, industrial hygiene and transportation safety that I have omitted, but I am using this means to portray an idea, not exact statistics. Note that we seem to have areas of much overlap and yet other areas where little or no safety effort is evident.

Yet, as we bend and twist to make our safety definitions (and others) fit, something else, somewhere else pops out and we have to start over again. Solving the definition problem is like trying to put together a jigsaw puzzle with pieces from several different puzzles.

A recent instruction issued by the Chief of Naval Operations is a step toward reducing some of this overlap. Now, if we have inadvertent detonation of a weapon aboard an aircraft, damaging the plane and injuring the pilot, only one report is required (rather than three). Incidentally it is OPNAV Instruction P3750.6F effective 1 July 1967 for those that are interested.

Right now you are probably saying to yourselves "So what!" So it means that the Services are all aware of the deficiencies and problems of the systems. Steps have been taken, not always successfully, to bring the thinking a little closer together. Joint meetings have been held and will continue to be held in efforts to make useful information available to other Services.

The Army and Air Force use codes to record accidents reported in their systems. In this fashion, statistics based on many variable parameters are available depending, of course, on available computer time.

All the Services are required to report accident statistics to the Department of Defense annually. Some of this information is classified but most is available.

All the Services tend to discourage or do not permit the general dissemination of specific explosive or missile accident reports because of security and legal reasons. However, general statistics are available, but remember, these statistics can only be compared with other statistics from the same Service. For example: a malfunction reported by a Marine organization gets into both the Army's and the Navy's statistics. So you can see that if I tell you the Army processes some 29,000 accidents a year remember that this includes all kinds of accidents; the Air Force some 500 accidents, 5,000 incidents and 20,000 other mishaps per year, remember that these are just explosive and missile mishaps; and the Navy just 600 accidents, incidents and malfunctions per year, remember that these are just explosive mishaps so don't jump to conclusions that "ain't necessarily so."

Assuming you have established the proper security clearance and a need-to-know, you could get this explosive safety information in the following publications or from the following offices:

Army: Safety Division (AMCAD-S)
Army Materiel Command
Nassif Building
Washington, D. C. 20315

Navy: Safety Division (ORD-932)
Naval Ordnance Systems Command
Main Navy Building
Washington, D. C. 20360

AF: Explosives Safety Branch (AFIAS-G2)
Directorate of Aerospace Safety, Hq USAF
Norton Air Force Base, Calif. 92409

Now I call upon Mr. Jezek of the Army Materiel Command and Mr. Schuyler of the Directorate of Aerospace Safety to back me up while I call for questions from you.

A/I INFORMATION REPORTING EFFORT

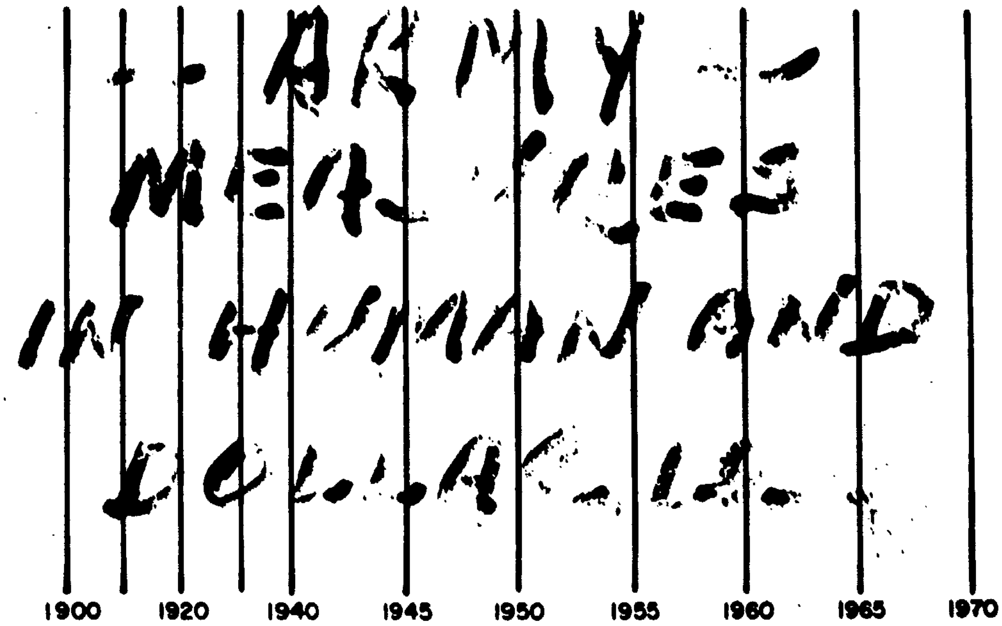


Figure 1

A/I INFORMATION REPORTING EFFORT

Figure 2

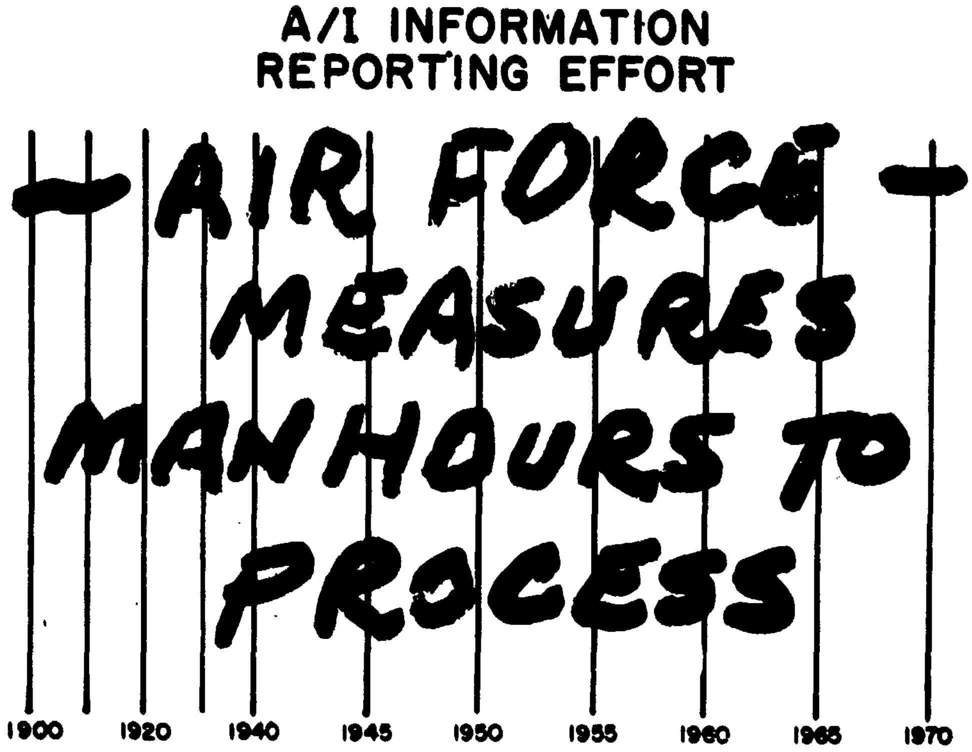


Figure 3

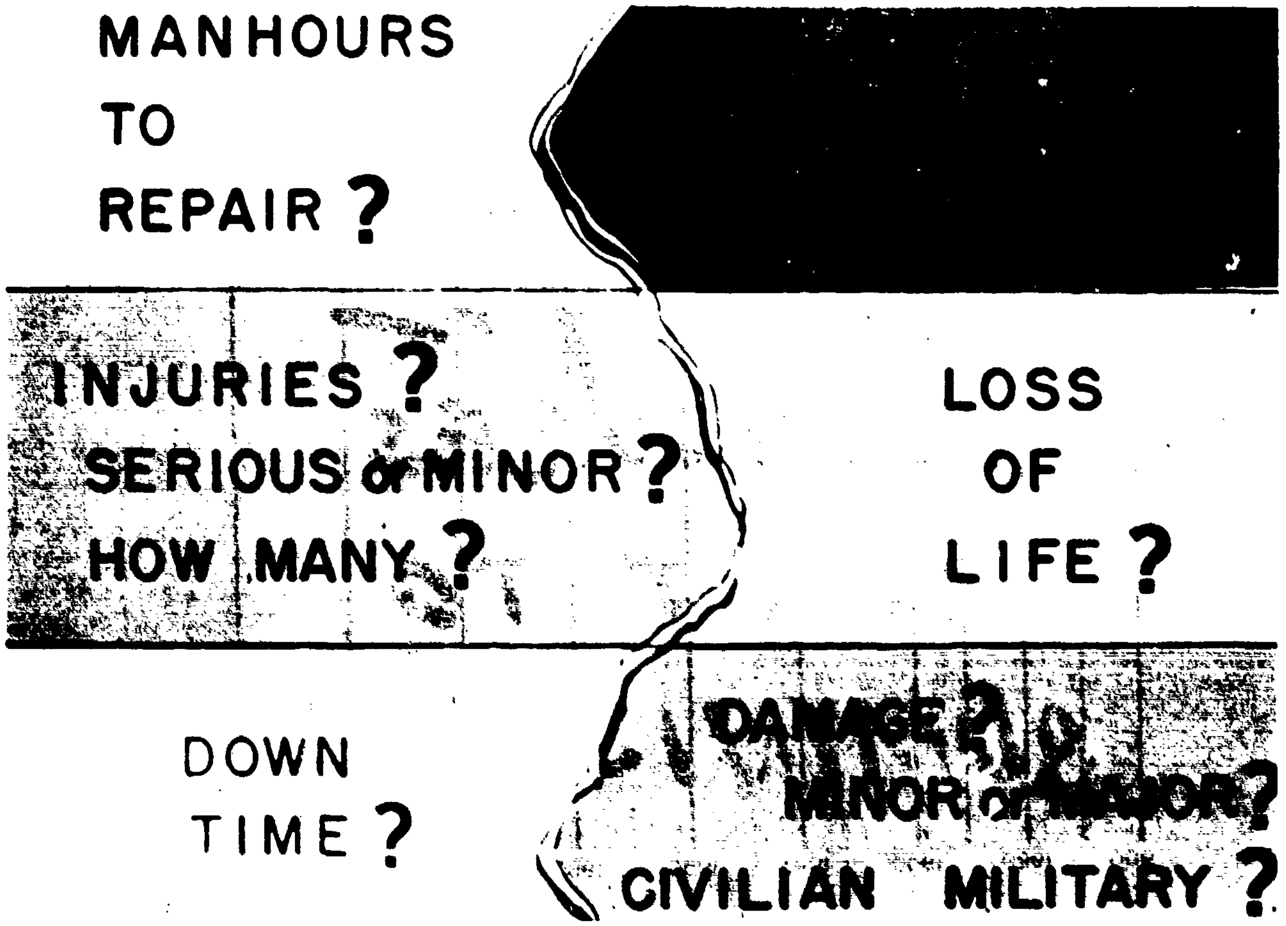


Figure 4

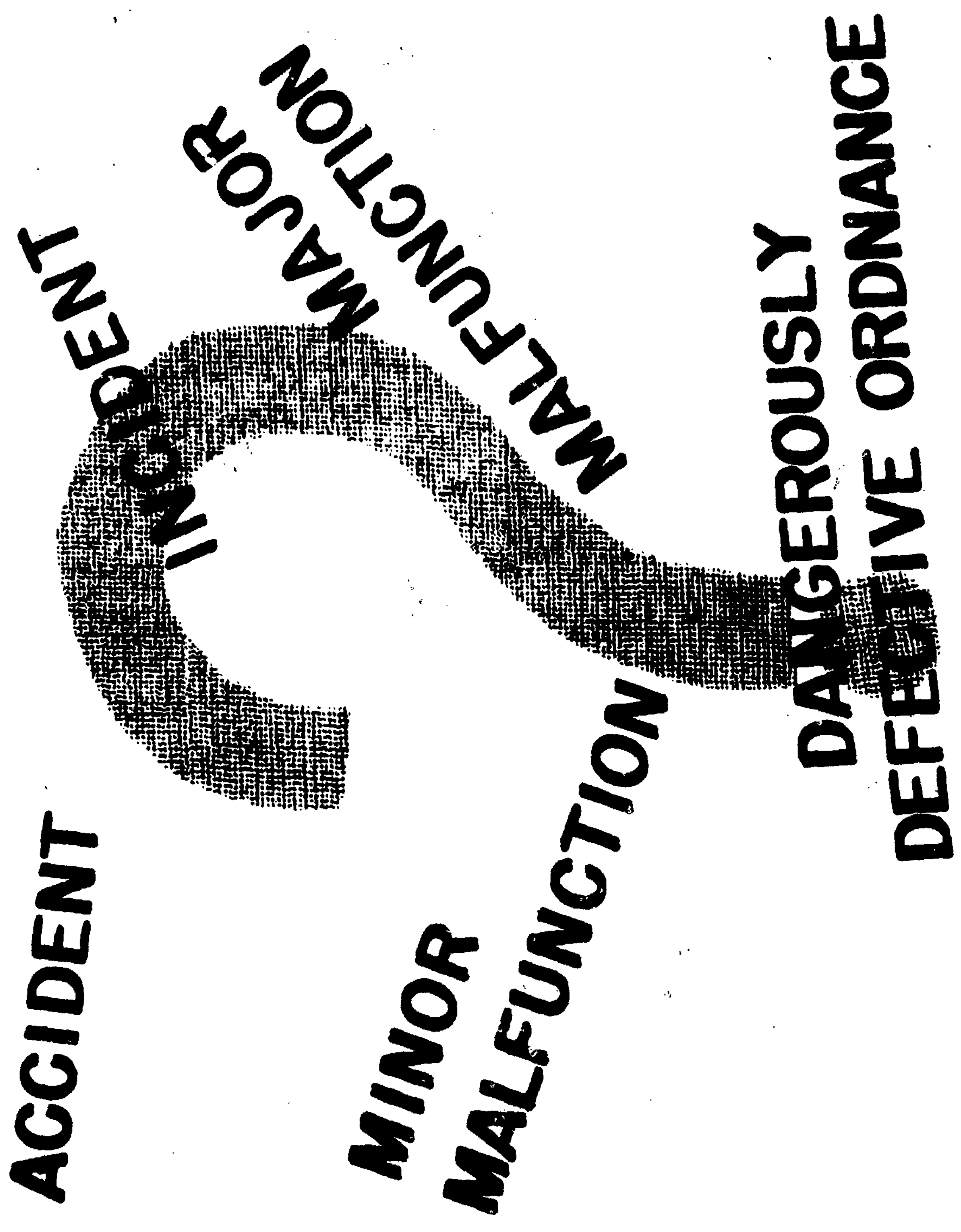

ACCIDENT
INCIDENT
MAJOR MALFUNCTION
MINOR MALFUNCTION
DANGEROUSLY DEFECTIVE ORDNANCE

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

EXPLOSIVE INCIDENT

DEPARTMENT OF THE NAVY
Bureau of Naval Weapons
Washington, D.C. 20360

BUWEPSINST 8020.6B
NWSA
FAM-51
8 February 1966

BUWEPS INSTRUCTION 8020.6B

From: Chief, Bureau of Naval Weapons
To: All Ships and Stations (less Marine Corps field addressees not having Navy personnel attached)

Subj: Accidents, malfunctions and incidents involving non-nuclear explosive ordnance and material

Ref: (a) U.S. Navy Regulations
(b) NAVWEPS Ordnance [illegible] (OP 4) (NOTAL)
(c) NAVWEPS Ordnance [illegible] (OP 5) (NOTAL)
(d) USMC Technical Instru[illegible] 15/1A (NOTAL)
(e) OPNAVINST 8110.16B [illegible]
(f) BUWEPSINST 5450.27

Encl: (1) Message Format
(2) Information Addressees

1. Purpose. To promulgate standard [illegible] for all naval activities in reporting [illegible] of accidents, incidents, and unsatisfactory performance of non-nuclear explosive [illegible] and material; and to provide for policies and responsibilities pertaining to subsequent corrective action.

2. Cancellation. This Instruction supersedes and

b. Explosive Material - All military and commercial explosives, in the bulk or [illegible] state, including formed but unassembled propellant grains. All separate or mixed [illegible] used in or associated with the production of explosives or explosive ordnance, which may burn or ex[illegible]. Included in this category is commercial [illegible] dynamite.

[illegible] accidental explo[illegible] or ex[illegible] inadvertent [illegible] resulting [illegible] damage to property.

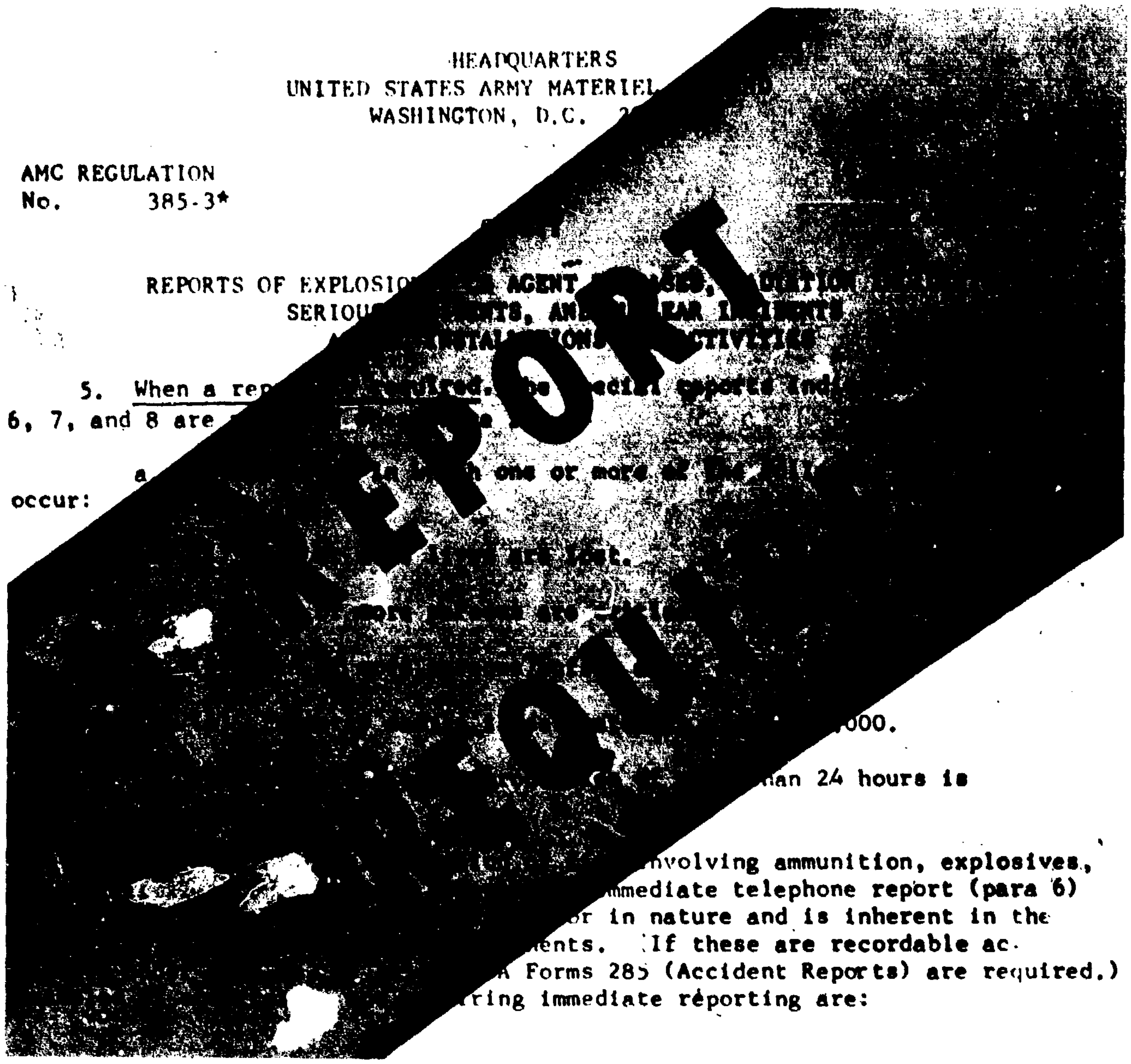
d. Explosive Incident - An occurrence which creates a potentially hazardous situation. Incidents include, but are not necessarily limited to:

[illegible]

(2) Unusual or unexpected occurrences, unnatural phenomena, unfavorable environments (i.e. RADHAZ), or instances of equipment failure which may damage or affect safety and reliability of explosives.

(3) Loss or abandonment of explosives resulting in potential hazard to untrained per[illegible] nel who ma[illegible] the ite[illegible]

Figure 10



HEADQUARTERS
UNITED STATES ARMY MATERIEL
WASHINGTON, D.C. 2

AMC REGULATION
No. 385-3*

REPORTS OF EXPLOSIO
SERIOU

5. When a re
6, 7, and 8 are

a
occur:

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an 24 hours is

nvolving ammunition, explosives,
mmediate telephone report (para 6)
r in nature and is inherent in the
ents. If these are recordable ac-
A Forms 285 (Accident Reports) are required.)
ring immediate reporting are:

Figure 11

EXPLOSIVE INCIDENT

AFR 127-4

AIR FORCE REGULATION
NO. 127-4

DEPARTMENT OF THE AIR FORCE
Washington, *28 June 1966*
Effective 1 July 1966

Safety

INVESTIGATING AND REPORTING USAF ACCIDENTS/INCIDENTS

5n. *Explosives Incident.* An event, condition, or environment which affects explosives and could cause an unintentional actuation, malfunction, fire, or explosion. This category includes explosives hazards and similar information which may be of value in explosives accident prevention.

Figure 12

HEADQUARTERS
UNITED STATES ARMY MATERIEL COM[illegible]
WASHINGTON, D.C. 20315

AMC REGULATION
No. 385-3*

SAFETY

REPORTS OF EXPLOSIONS, CB AGE[illegible]
SERIOUS ACCIDENTS [illegible]
AT AMC INSTAL[illegible]

5. When a report is requir[illegible] 6, 7, and 8 are required when t[illegible]

a. Any accident i[illegible] occur:

(1) One [illegible]

(2) [illegible]

(3[illegible]

proba[illegible]

[illegible]on, explosives, [illegible] report (para 6) [illegible] inherent in the [illegible] recordable ac- [illegible] Reports) are required.) [illegible]ng are:

Figure 13

EXPLOSIVE ACCIDENT

AFR 127-4

AIR FORCE REGULATION
NO. 127-4

DEPARTMENT OF THE AIR FORCE
Washington, 28 June 1966
Effective 1 July 1966

Safety

INVESTIGATING AND REPORTING USAF ACCIDENTS/INCIDENTS

SECTION A—GENERAL

SECTION B—EXPLANATION OF TERMS

5m. *Explosives Accident.* An explosion or fire involving ammunition or explosives which is not specifically defined in this regulation as an aircraft, missile, or nuclear accident/incident. These mishaps would include premature detonation or ignition, structural failure or breakup of nonnuclear munitions after intentional release or delivery from aircraft provided such occurrence does not result in aircraft damage.

Figure 14

EXPLOSIVE ACCIDENT

DEPARTMENT OF THE NAVY
Bureau of Naval Weapons
Washington, D.C. 20360

BUWEPSINST 8020.6B
NWSA
FAM-51
8 February 1966

BUWEPS INSTRUCTION 8020.6B

From: Chief, Bureau of Naval Weapons
To: All Ships and Stations (less Marine Corps field addresses not having Navy personnel attached)

Subj: Accidents, malfunctions and incidents involving non-nuclear explosive ordnance and material

Ref: (a) U.S. Navy Regulations
(b) NAVWEPS Ordnance Pamphlet 4 (OP 4) (NOTAL)
(c) NAVWEPS Ordnance Pamphlet 5 (OP 5) (NOTAL)
(d) USMC Technical Instruction TI-8010-15/1A (NOTAL)
(e) OPNAVINST 8110.16B (NOTAL)
(f) BUWEPSINST 5450.27

Encl: (1) Message Format
(2) Information Addressees

1. Purpose. To promulgate standard procedures for all naval activities in reporting occurrences of accidents, incidents, and unsatisfactory performance of non-nuclear explosive ord[illegible]

b. Explosive Material - [illegible] commercial explosives, [illegible] including [illegible] grains. [illegible] or [illegible] or [illegible]

c. Explosive Accident - An accidental explosion or fire involving explosive ordnance or explosive material. This includes the inadvertent actuation, jettison, release or launching of explosive ordnance resulting in fire, and/or explosion and damage to property.

d. Explosive Incident - An [illegible] creates a potentially hazardous situation. Incidents include, but are not necessarily limited to:

(1) Human errors in processing, assembly, testing, loading, storing, transporting, handling, using, or disposal of explosives.

(2) Unusual or unexpected occurrences, unnatural phenomena, unfavorable environments (i.e. RA[illegible] or [illegible] of equipment fail-

Figure 15

SECTION II

DEFINITIONS AND INTERPRETATION OF TERMS

5. Army accident. An unplanned event resulting in injury to a person or damage to equipment or property incident to an Army operation or activity that is not the result of combat operations or *direct* action by a hostile or belligerent force.

6. Hazardous condition. A defect or inadequacy in material which constitutes a potential accident cause that may result in injury to persons or damage to property.

[redacted]

7. Vertical and horizontal stabilizers.

8. Undercarriage upper cylinder assemblies and fuselage attaching points only (excl...

Figure 16

MISSILE ACCIDENT/INCIDENT

AIR FORCE REGULATION
NO. 127-4

DEPARTMENT OF THE AIR FORCE
Washington, *28 June 1966*
Effective 1 July 1966

Safety

INVESTIGATING AND REPORTING USAF ACCIDENTS/INCIDENTS

d. *Missile Accident.* A mishap resulting [illegible] damage to a USAF missile or OGE and involves:

(1) Fatality or major injury.

(2) Damage in excess of $10,000 to Government or private property as a result of launch. The cost of missile and normal residual launch damage is excluded.

(3) Impact of launched missile or its debris outside the designated safety area or on private property.

(4) Destruction or damage to missile or OGE, not as a result of launch, which requires 250 or more direct manhours to repair and/or replace damaged component.

(5) Inadvertent launch.

(6). Unprogrammed breakup in flight or [illegible] destruction of ground-launched, [illegible]. This also applies to AGM [illegible]

e. ***Missile Incident.*** **A mishap which does not qualify as an accident and involves any of the following:**

(1) Reparable damage to missile or OGE, not as a result of launch, which requires less than 250 direct manhours to repair and/or replace damaged components.

(2) Failure to launch resulting in damage to missile.

(3) Unprogrammed breakup in flight, premature arming, or detonation of warhead or destruct system.

(4). Post-launch malfunction which results in flight failure or destruction of missile.

(5) Failure of destruct system to perform as designed after launch.

(6) Intentional controlled jettison when such jettison is necessitated by missile malfunction.

Figure 17

EXPLOSIVE ACCIDENT

DEPARTMENT OF THE NAVY
Bureau of Naval Weapons
Washington, D.C. 20360

BUWEPSINST 8020.6B
NWSA
FAM-51
8 February 1966

BUWEPS INSTRUCTION 8020.6B

[illegible] Bureau of Naval Weapons
[illegible] and [illegible] Marine Corps
[illegible] having Navy person-
[illegible])

Subj: Accidents, malfunctions and incidents involving non-nuclear explosive ordnance and material

Ref: (a) U.S. Navy Regulations
(b) NAVWEPS Ordnance Pamphlet 4 (OP 4) (NOTAL)
(c) NAVWEPS Ordnance Pamphlet 5 (OP 5) (NOTAL)
(d) USMC Technical Instruction TI-[illegible] 15/1A (NOTAL)
(e) OPNAVINST 8110.16B (NOTAL)
(f) BUWEPSINST 5450.27

Encl: (1) Message Format
(2) Information Addressees

1. Purpose. To promulgate standard procedures for all naval activities in reporting occurrences of accidents, incidents, and unsatisfactory performance of non-nuclear explosive ordnance [illegible]

b. Explosive Material - All [illegible] mercial explosives, [illegible] including [illegible] grains [illegible] or [illegible] or [illegible] or military [illegible]

c. Explosive Accident - An accidental explosion or fire involving explosive ordnance or explosive material. This includes the inadvertent actuation, jettison, release or launching of explosive ordnance resulting in fire, and/or explosion and damage to property.

d. Explosive Incident - An [illegible] creates a potentially hazardous [illegible] dents include, but are not necessarily limited to:

(1) Human errors in processing, assembly, testing, loading, storing, transporting, handling, using, or disposal of explosives.

(2) Unusual or unexpected occurrences, unnatural phenomena, unfavorable environments (i.e. RAD[illegible] or [illegible] of equipment fail-

Figure 18

Overall
Navy
Safety

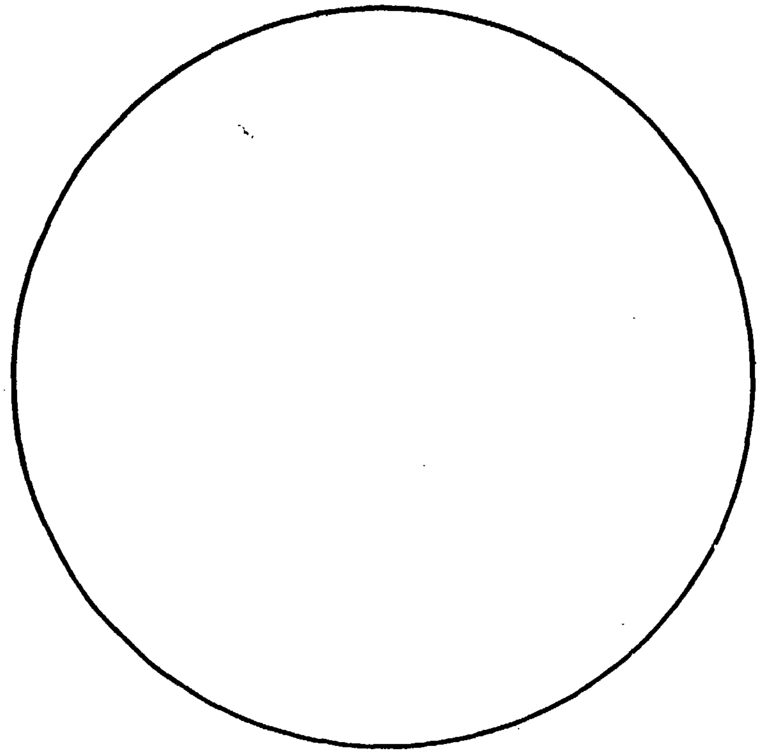


Figure 19

Overall
Navy
Safety

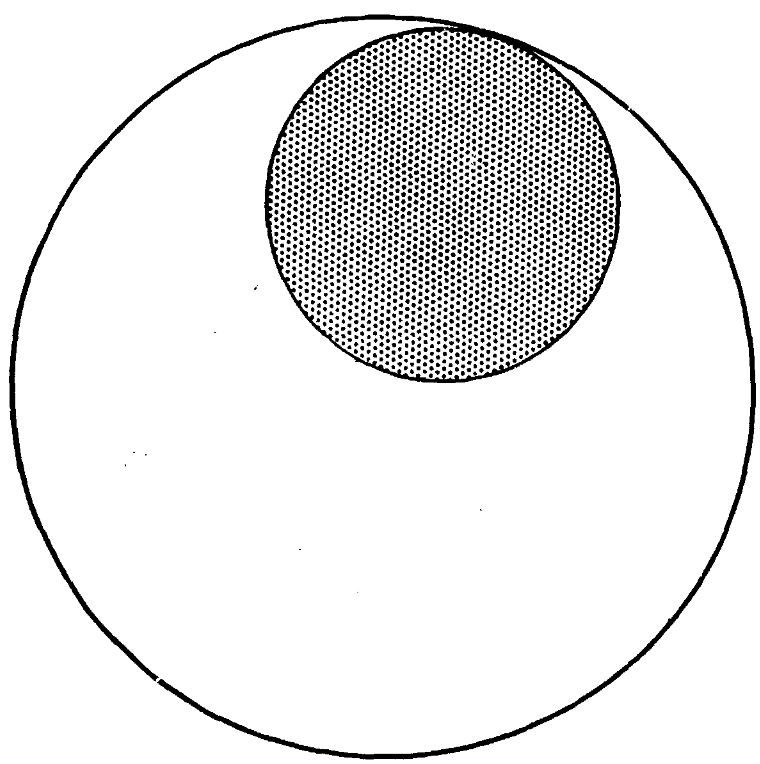


Figure 20

Overall Navy Safety

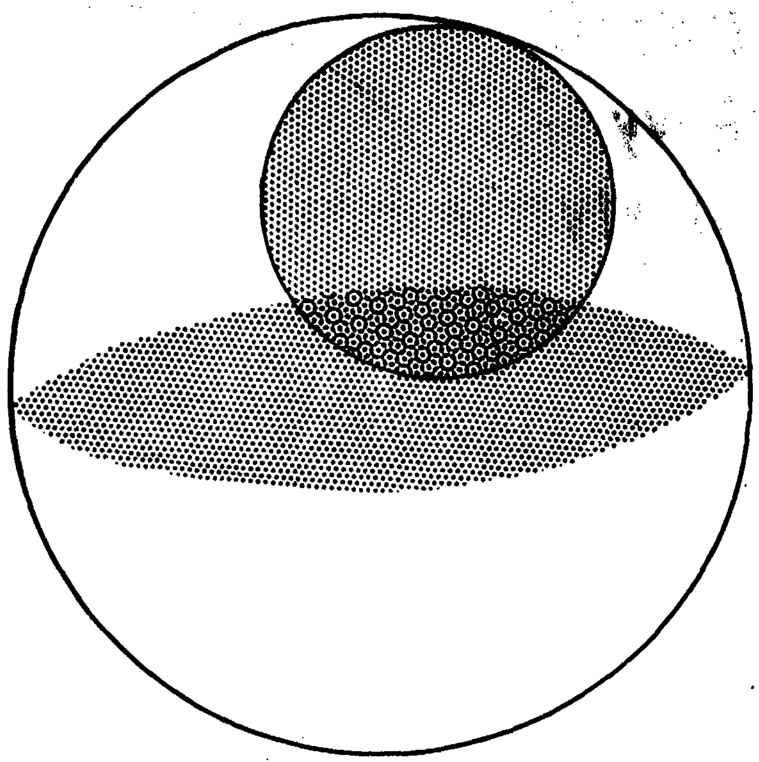


Figure 21

Overall Navy Safety

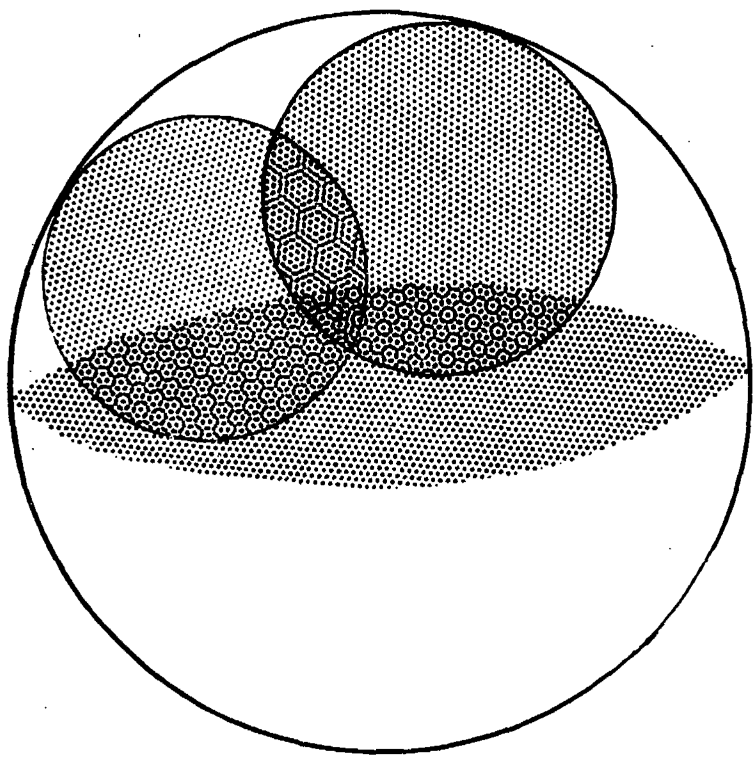


Figure 22

Figure 23

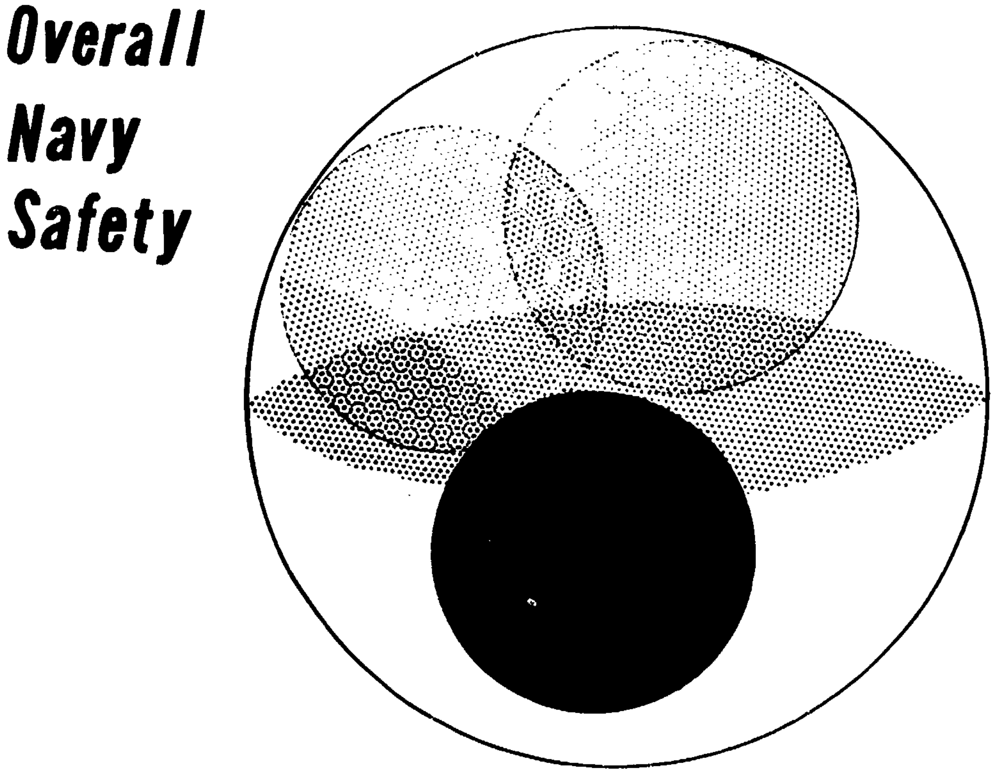


Figure 24

Overall Navy Safety

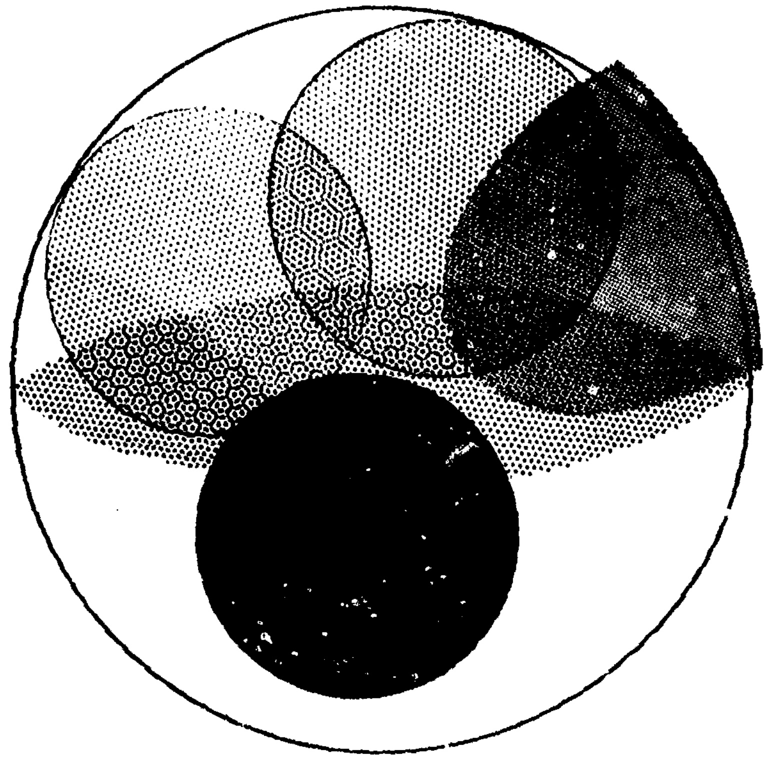


Figure 25

Overall Navy Safety

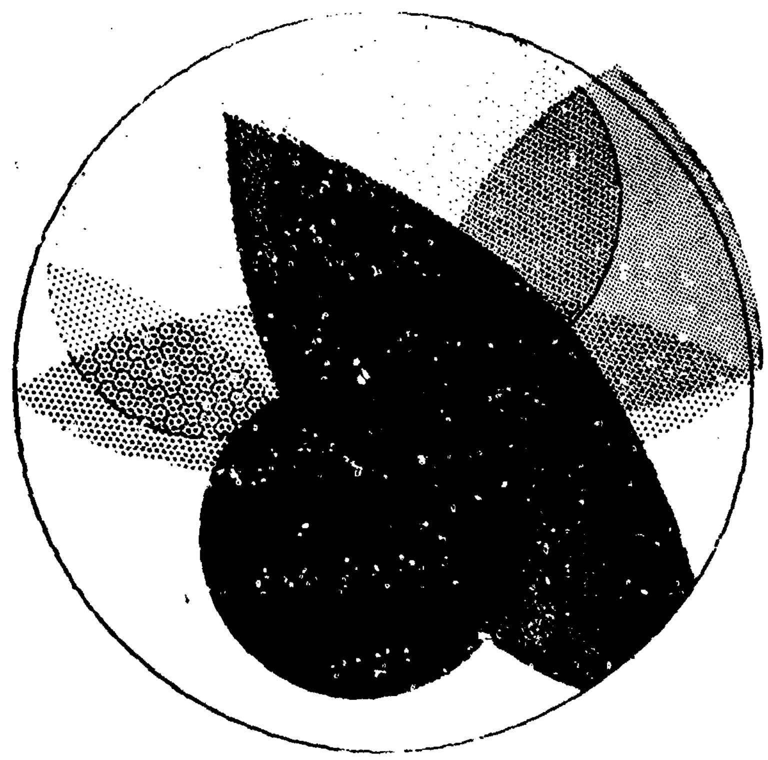


Figure 26

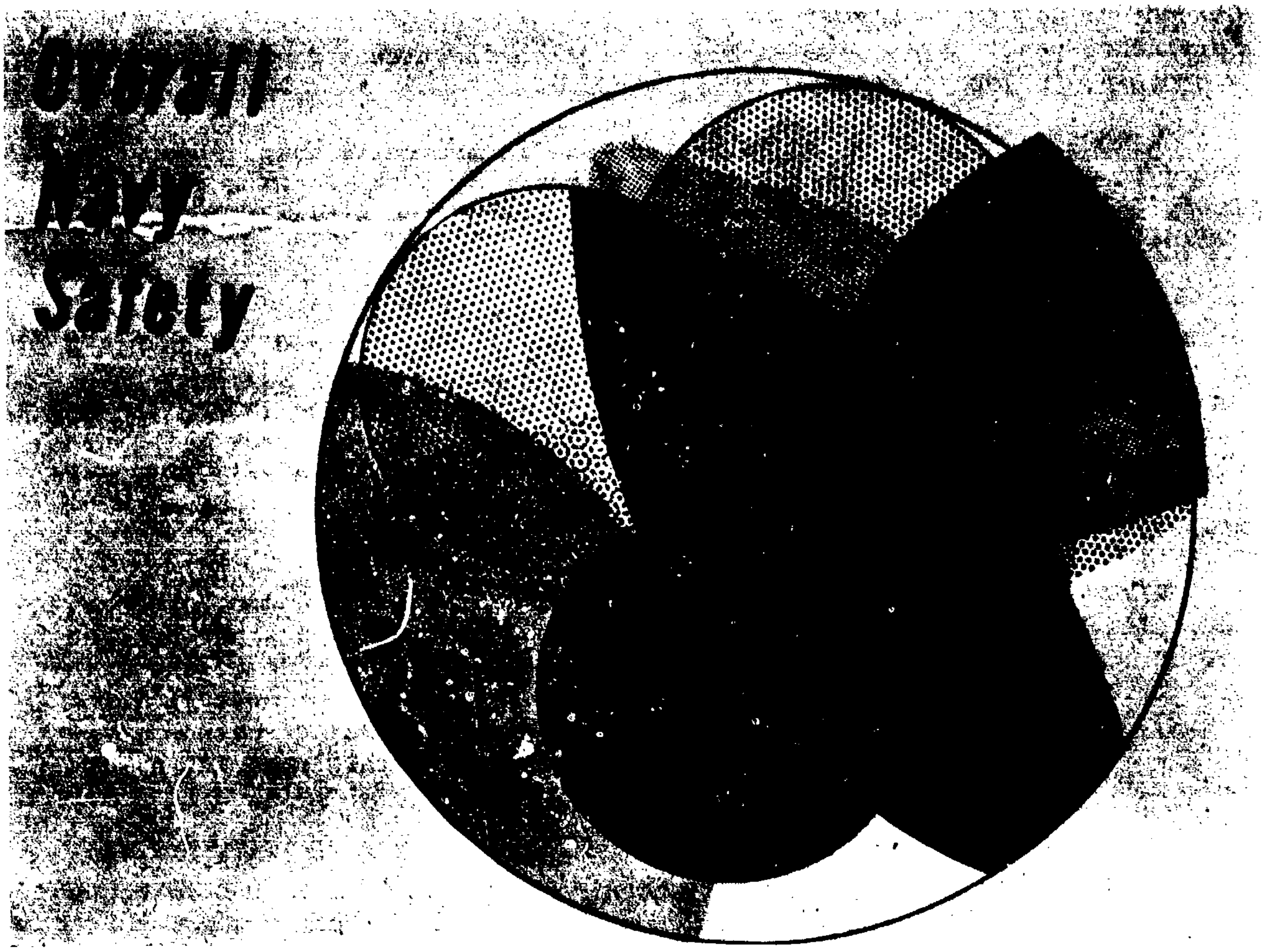


Figure 27

D. J. SAVORY, USA MUNITIONS COMMAND: At present is there a tri-Service body set up to come up with uniform definitions for reporting of accidents, incidents, malfunctions, etc.?

BIRON: I know of no organization that is presently doing this. No, there is no tri-Service organization. I don't even think there is an individual Service organization that's working on the explosives safety definition picture.

SAVORY: It would appear to me appropriate at this time to let this be a start of some such inter-Service collaboration on standard definitions. In the Army Materiel Command and Munitions Command we have gotten together on inter-command collaboration on such things but I believe it should go across-the-board and eliminate these multiple reporting systems within each Service as you have done in Navy. This is a very good idea so I'd like to talk to you later on it and see what could really be started to set up some tri-Service effort.

BIRON: As far as definitions are concerned, I say the Air Force has come closest with their 127-4 where they tried to cover all types. Right now our definitions within the Navy have some overlap because of the parent command. I don't know whether you have that in the Army or not. I think the Air Force has at least taken a good step in the right direction to get all their definitions at least into one document and this makes it a lot easier to look it up.

A. R. O'KONSKI, DCASR NEW YORK: The question is as follows. Of the three Services, are the accidents that are being reported to DoD in-house accidents, or do they include accidents on contracts? Or let's add possibly on contractor operated arsenals. What do all these accidents entail?

BIRON: The Army's answer.

LOU JEZEK, ARMY MATERIEL COMMAND: We don't report contractor accidents to DoD. I think if anyone would do that it would be DCAS at Cameron Station. As far as definitions are concerned, of what should be or should not be reported insofar as the Army Materiel Command is concerned, we have a regulation AMCR 385-3. If you will read that there shouldn't be any excuse as to what should or shouldn't be reported. But I always say, when in doubt, report.

PHIL SCHUYLER, HQ USAF, NORTON AFB: Our contractors do not report to the Air Force system except on an informational basis. It is my understanding that it's not included in Air Force statistics. I'm not extremely well versed in the inner ramifications of the Air Force's reporting system under the code of AFIAS-R but to say this - we'll take care of the Commander's charts by stating that 127-4 is in the process of a rather sweeping division. It will further define accident incident categories and their overlap into the aircraft accident system. For instance, a bomb or a rocket or a missile going off under an airplane and causing an aircraft loss will be

a major aircraft accident obviously. And that's the way the Air Force is going to carry it. So in addition to explosive mishaps, to use that term, we in explosives safety worry about the aircraft accidents or incidents that were caused by explosives. This is punched separately in the channel system in the Air Force reporting system. For computer time, they're making a major installation in our headquarters in that direction and we hope some of the information will be a little more readily retrievable. We've had problems in that connection in getting meaningful data on a spur-of-the-moment basis about trends on individual items. So we've had our problems. I hope they're toward a solution and I'm sure the Air Force would be willing to join any inter-Service discussion about consolidating definitions but as mentioned by the commanders, problems are so vastly different and our organizational structure is different, that the uses we make of these data almost require or dictate the definitions that have been adopted by our reporting people. So in making the shoe fit us, the Air Force, we probably would come up with different solutions than certainly the Navy. I don't know how we could come to that point of complete consolidation or not and still get the best use of our data.

R. R. ROUSH, LOCKHEED MISSILES & SPACE CO.: It seems there may be one gentleman missing from your group and that's NASA. Is there anyone here that could join the group and be able to give us some information concerning the same type of thing for NASA, especially MILA areas, and maybe a document that would be applicable to the safety in that area.

E. E. HARTON, HQ NASA: I'm Erskine Harton, Acting Safety Director for NASA. We're in the process now of developing automatic data processing for reporting and analyzing accident (injury, damage failure and loss) information. At the moment we're doing this strictly on the injury experience which is required as a monthly report and on a quarterly cause analysis report. We hope to get a pilot operation started in the fall eventually leading into entire coverage throughout NASA and ultimately then spread over to the contractor operations. In our case we're outnumbered personnel-wise about 10-to-1 by our contractors and we feel that this is one possible management tool which can be used to evaluate safety programs which we are now requiring of our contractors through safety clauses in the contracts.

It has been a rather slow process and we have been working with the group, Maj. Sorenson's group at Norton AFB. I believe they refer to it as the TAP program. This deals strictly initially with flight safety and accident aspects. I know they have been working very closely with the Navy flight safety people at Norfolk. We hold informal get-togethers with them (TAP people) occasionally to try to eventually come up with something that would be compatible.

But as far as having the complete details worked out, this will take some time. We hope to eventually do this, because we feel that by getting the information ahead of time, we may spot trends and rather than have to report accidents we would be able to spot troubles ahead of time and prevent them before they did become an accident. In other words,

this would be an ahead-of-the-time approach as against after-the-fact. But its no simple matter as you've pointed out and we've got a long way to go.

Editor's Note:

To more specifically answer the question posted, Mr. Harton, subsequent to the meeting, furnished the following list of NASA Regulations which pertain all, or in part, to accident reporting:

a. NASA Management Instruction (NMI) 1710.1A dated July 11, 1967 entitled "NASA Safety/Accident Prevention Plan."

b. NMI 1711.1A dated October 24, 1966 entitled "Reporting, Investigation, and Action on Serious Accidents/Incidents Involving NASA Employees, Resources, or Property."

c. NMI 1712.1 dated October 2, 1964 entitled "Reporting and Analysis of Injuries Involving NASA Employees."

d. NMI 1136.8A dated May 27, 1966 entitled "Functions and Authority - NASA Safety Director."

e. NASA Policy Directive (NPD) 1711.2 dated October 24, 1967 entitled "Reporting, Investigation, and Action on Serious Accidents/ Incidents Involving NASA Employees, Resources, or Property."

TNT EQUIVALENCY-GAS DYNAMICS COMPARISON FOR MODERATELY PRESSURIZED TANKS

R. A. Boudreaux
Space Division
North American Aviation, Inc.
Downey, California

INTRODUCTION

The sizes, shapes, and utilization of pressurized tanks cover too broad a range to be characterized by any single method of predicting potential destructive energy in the event of tank wall failure. High pressure systems are less influenced by environmental pressures; small systems dissipate proportionately more energy in accelerating wall fragments as do ASME coded vessels with walls designed with a safety factor of 4 compared to values approaching 1 for rocket propellant tanks; spherical tanks have the greatest potential for symmetrical dispersion of shock waves and fragments; and failure mode has the final influence on the basic destructive nature accompanying tank wall failure. These variables by no means comprise the spectrum of influences on destructive potential and, therefore, one must rely upon emperical correlations used with realistic safety factors where geometries differ between correlation and application.

In arriving at an analytical procedure to permit safe handling and use of pressurized tanks in the event of burst failure, the analysis must be conservative enough to accommodate probable uncertainties without being so conservative as to be overly costly in terms of isolation distances and facilities[1]. This factor is of appreciable economic importance relative to present day large rocket propellant tanks which undergo static pneumatic pressure tests.

It is customary to project the destructive energy of detonating or pressure caused bursting systems in terms of equivalence to a standard yield of TNT. This trend has generally been followed in spite of the natural tendency to want to analyze expanding pressurized systems in terms of pure gas dynamics wherein shock strengths may be determined without resort to a TNT equivalence. This is partly because the mode of failure controls the rate and direction of energy release; the terrain dominates shock reflection and re-phasing; atmospheric conditions influence shock propagation; and the prevailing wind direction generally focuses the far field shock pattern. Additionally, the nebulousness of the relative energy associated with fragment dispersion and the need for the prediction of the dispersion pattern and range cause one to consider a TNT equivalence since there is a large body of correlated explosives data which randomly includes all of the variables above.

This paper is primarily concerned with large, thin walled tanks at moderate pressures. Systems of this type are expected to have shock fronts of 10 to 40 millisecond duration[2] and the energy associated with fragment acceleration is neglected. An adiabatic expansion process is assumed and comparisons are made between the results of gas dynamic and TNT equivalency considerations.

SUMMARY

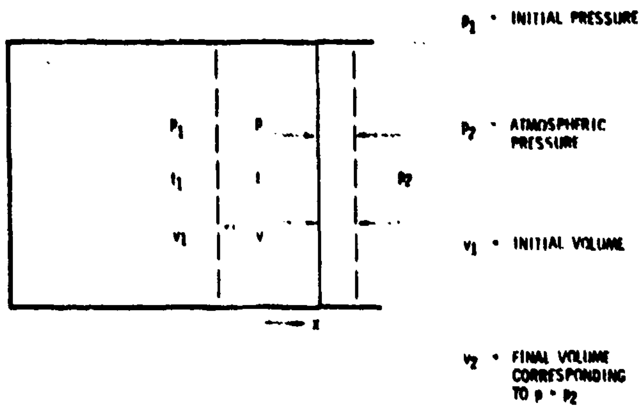
For large volume, low energy density pressurised tanks, the most suitable manner of considering the work done against atmospheric pressure during expansion and thermodynamic characterisation of the process was explored. Adiabatic expansion with and without consideration of work done against atmospheric pressure was considered. It was shown that the TNT equivalencies predicted by the two methods differed appreciably for tank pressures of approximately 100 psig or less, the working pressure range of current large booster rocket stages.

Gas dynamic considerations included a variable area shock tube analogy comparison with the developed TNT equivalency. Pressure/distance trends differed somewhat but allow increased insight for near-in distances where a TNT point source is not really representative of a large, low energy-density tank.

A comparison of the developed analytical procedures with test data from an Atlas destruction test shows good correlation but emphasizes the need to properly assess geometry influences.

POTENTIAL ENERGY COMPARISONS

In previous destructive energy predictions for aircraft pressure cabins[3], the adiabatic expansion of air against the atmosphere was considered based on the piston analogy as follows:



The net force on the piston bulkhead is $(p-p_2)A$ and the net work performed during expansion is

$$dw_{net} = (p-p_2)Adx = (p-p_2)dv \tag{1}$$

Assuming an adiabatic expansion,

$$pv^{\gamma} = p_1 v_1{}^{\gamma} = p_2 v_2{}^{\gamma} = \text{const}, \tag{2}$$

and integrating, there results

$$w_{net} = 144 p_2 v_1 \left(\frac{p_1}{p_2}\right)^{1/\gamma} \left\{ \frac{\gamma}{1-\gamma} - \left(\frac{p_2}{p_1}\right)^{1/\gamma} \left[\left(\frac{1}{1-\gamma}\right)\left(\frac{p_1}{p_2}\right) - 1\right]\right\} \tag{3}$$

The equivalent TNT quantity then is the ratio of the work of expansion above, to a standard energy release of TNT. Although the standard TNT yield varies somewhat on the literature, the following equivalency is adopted here.

$$w_{TNT} = \frac{w \text{ (ft-lb)}}{1.425 \times 10^6 \left(\frac{\text{ft-lb}}{\text{lb TNT}}\right)} \tag{4}$$

The piston analogy as presented above simply represents the change of thermodynamic energy state of the system minus external work. For a piston application, the net useful work differs from the energy release since the energy absorbed by the atmosphere is dissipated independently of the applied load. For the tank rupture case, even though the atmosphere has absorbed some of the released energy, the effect on the absorbing atmosphere is an increased pressure and temperature in the form of a wave front which eventually must transmit and/or internally dissipate the energy. Thus, the atmospherically absorbed portion of the released energy will not necessarily be dissipated independently of the applied load.

Based on this consideration, then, the total potential energy release should be considered in determining the TNT equivalency. Or

$$w = \int_{v_1}^{v_2} pdv = \frac{p_1 v_1 - p_2 v_2}{\gamma - 1}$$

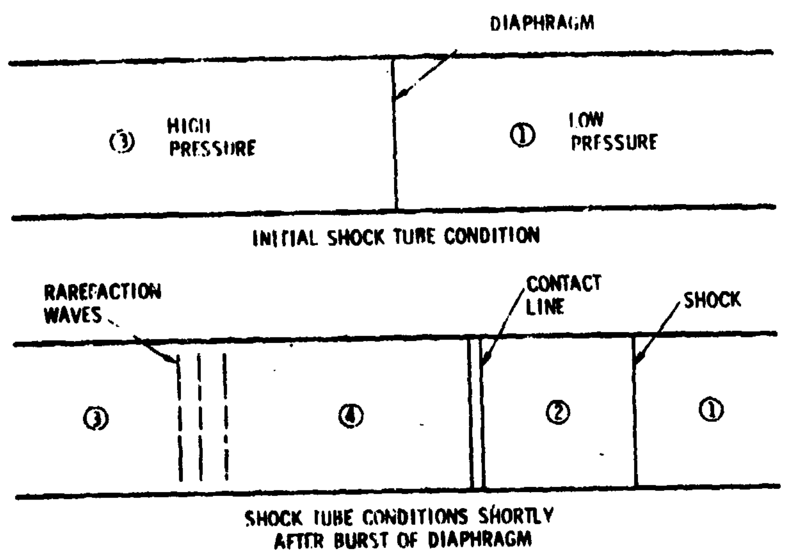
$$= \frac{144 v_1}{1-\gamma}\left[p_2\left(\frac{p_1}{p_2}\right)^{1/\gamma} - p_1\right]. \tag{5}$$

As a comparison, in Figure 1 Equations (3) through (5) are combined into two working equations and a comparison of the resulting TNT equivalencies for a 1000 ft^3 vessel as a function of tank pressure is presented (compressibility ignored). From this figure, it is seen that at the lower pressures there is a sizable discrepancy between the TNT equivalencies when including the work performed on the ambient and when not. At the higher pressures, the equivalence predictions assympotically merge so that the choice of prediction method has little effect on the answer. Because the pressure levels of interest for large rocket tanks are generally under 100 psig, the region of interest is that in which the large discrepancy arises between the two prediction methods. For this reason, an analysis based on gas dynamic considerations alone was undertaken.

GAS DYNAMIC CONSIDERATIONS

Near-In Pressure Field Review of the literature indicates that previous "exact" and numerical solutions to the blast problem have all considered high yield processes not directly suitable to the near-in concern of the present case.[4,5,6] As a practical approach to the moderately pressurized tank problem, a shock tube analogy was considered.

In order to provide a shock tube analogy of the pressurized tank, the initial shock strength has to be determined. This was accomplished by considering a one-dimensional shock as follows:[7]



The strength of the shock wave is determined by the static pressure ratio p_2/p_1. Since only the initial pressure ratio p_3/p_1 is known, an iterative solution is required of the following equation in order to determine the initial shock wave Mach number M_i.

$$\frac{p_1}{p_3} = \frac{p_1}{p_2}\left[1 - \left(\frac{\gamma-1}{2\gamma}\right)\frac{\left(\frac{p_2}{p_1} - 1\right)}{\sqrt{1 + \frac{\gamma+1}{2\gamma}\left(\frac{p_2}{p_1} - 1\right)}}\right]^{2\gamma/\gamma-1} \tag{6}$$

For spherical or cylindrical shock waves, the change in Mach number associated with change in cross sectional area is given by[8]

$$\frac{\delta A}{A} = \frac{-2M\ \delta M}{(M^2-1)\ K(M)}, \tag{7}$$

where

$$K(M) = 2\left[(1 + \frac{2}{\gamma+1}\ \frac{1-\mu^2}{\mu})(2\mu + 1 + M^{-2})\right]^{-1}$$

$$\mu^2 = \frac{(\gamma-1)\ M^2 + 2}{2\gamma M^2 - (\gamma-1)}$$

Equation 7 was generated for small area changes but this equation has been suggested as useful when the cross sectional area varies continuously without restriction to small perturbations. With this in mind, and realising that K(M) varies only from 0.5 to 0.3941 ($\gamma = 1.4$) as M varies from 1 to ∞, Equation 7 can be integrated while assuming K(M) is constant over a small Mach number range to yield

$$A^{K(M)}(M^2 - 1) = \text{constant}, \tag{8}$$

or

$$M_f = \left[1 + \left(\frac{A_i}{A_f}\right)^{K(M)}(M_i^{\,2} - 1)\right]^{1/2} \tag{9}$$

where M_i and A_i are initial Mach number and Area and M_f and A_f are the corresponding conditions at any point in question. For initial pressures below 100 psig, $\overline{K(M)} \approx 0.5$, and Equation 9 is approximated by

$$M_f = \left[1 + \left(\frac{A_i}{A_f}\right)^{1/2} (M_i^2 - 1)\right]^{1/2} \qquad (10)$$

where M_i = Initial Mach number

A_i = Surface area of tank.

For cylindrical shocks

$$\left(\frac{A_i}{A_f}\right)^{1/2} = \left(\frac{2\pi r_i l}{2\pi r_f l}\right)^{1/2} = \left(\frac{r_i}{r_f}\right)^{1/2} \qquad (11)$$

Distant Pressure Field While the suitability of the analysis of the preceding section is based on the relatively small distance between tank and blast wave impingement, it is interesting to expand the analysis to predict effects at large distances for comparison with blast data.[9] It should be expected that the shock tube analogy will over-predict the pressures at large distances because the employed equations do not account for viscous and inertia effects of the ambient and, therefore, ignore atmospheric dissipation. The shapes of the resulting pressure-distance curves are of interest, however, and by comparing these curves to TNT ground blast curves, some insight is gained relative to the effects of ground reflection on blast propagation.

The effects of nuclear weapons are studied in detail in Reference (10). In particular, reflected overpressure data are given in Figure 371b of this reference. Although these data are specified for reflection from buildings, etc., they are also applicable to ground reflection from air bursts. For normal impingement (90°), the controlling equations reduce to the simple Rankine-Hugoniot relationship for air

$$P_r = 2P_{op} \frac{7\ P_{am} + 4\ P_{op}}{7\ P_{am} + P_{op}} \qquad (12)$$

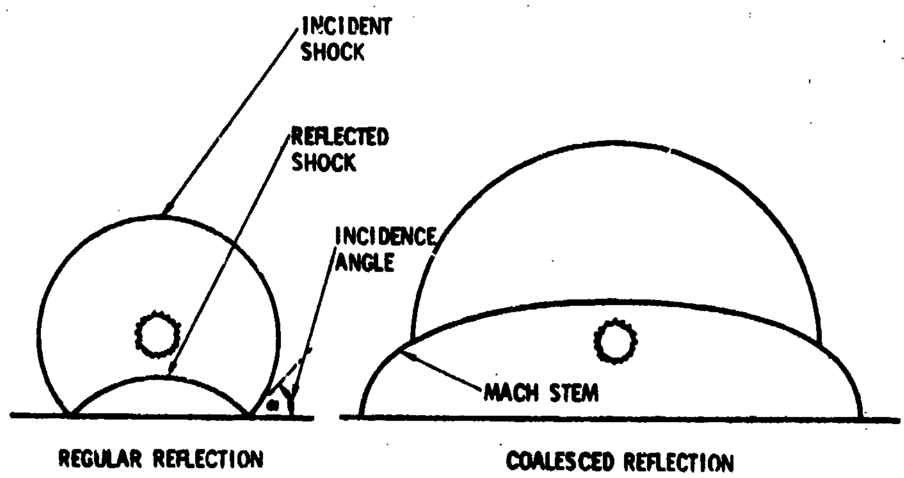
where

P_r = reflected overpressure, psig

P_{am} = ambient pressure, psia

P_{op} = unreflected overpressure, psig

Some attention should be given here to the atmospheric propagation of shock waves from gross considerations in order to apply the data of Figure 371b. For an air burst, there is a time lapse before the shock wave reaches the ground. Upon reflection, depending on the radial position under consideration, there is a finite distance between the incident and reflected shock fronts. For a high energy yield, such as from an explosive charge, the reflected shock travels in a heated region while the incident shock travels in an unheated region and thus the reflected shock tends to catch up to the incident shock. The region wherein the shocks coalesce is known as the Mach stem and the peak overpressure behind the Mach stem shock usually is twice the value of the incident shock. Prior to the coalescense of the incident and reflected shocks, the region of reflection is known as Regular Reflection and the strength of the reflected wave is determined from Figure 371b of Reference (10). It should be pointed out also that the parametric curves of Figure 371b again indicate that the value of reflected pressure to unreflected overpressure tends toward a value of 2 as the incident shock wave approaches 90° which is appropriate for the Mach stem region.



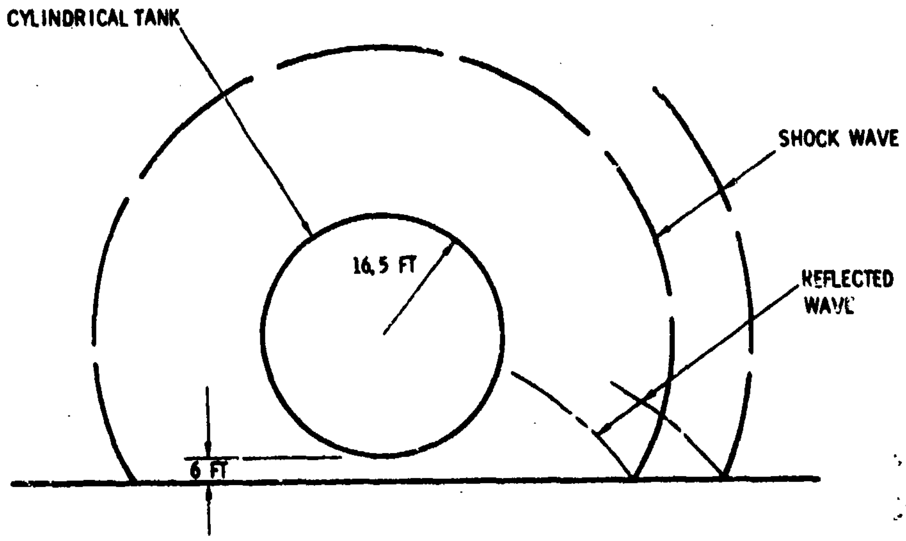
Tank Partially Filled with Bulk Materials Future tests may be considered which would use bulk fill material such as ping-pong balls or styrofoam logs to occupy much of the internal tank volume and thus greatly reduce the quantity of air within the tank when pressurized. It is of interest to determine the resulting shock strength should the tank rupture under such conditions.

A simple model comes to mind wherein one might imagine an inner tank symmetrically standing off from the original tank inner wall. If only the volume between the two tanks were pressurized and then the outer tank uniformally ruptured and instantaneously removed without loss of internal energy, the shock strength would in essense be identical to that of the un-bulk filled tank of the previous sections. Pulse widths, pulse phasing, and probably atmospheric attenuation would be modified. While this is an ideal view, it should also be realistically emphasized that for small gap distances, most of the energy of the contained gas would be absorbed in accelerating tank fragments thereby greatly diminishing shock front effects.

Utilizing the proposed bulk-fill techniques above, however, the pressurized air is uniformally distributed between the bulk material volumes and the ideal initial wave front is no longer homogeneous pressurized gas, but gas and bulk material. Thus, if the tank wall were instantaneously removed as before, expansion in the radially outward direction would be immediately accompanied by Prandtl-Meyer expansion around the bulk materials so that the effective outward radial shock velocity would be greatly reduced. Also, the bulk material and tank wall fragment masses would be accelerated by the intervening pressure differentials and would "soak-up" much of the compressed gas energy. For this case, it could be expected that the isentropic change of state of the interstitial gas would yield shock overpressures which are substantially greater than would actually be experienced. At any rate, using the adiabatic change of state of the interstitial gas should give conservative results.

HORIZONTAL TANK EXAMPLE

In order to compare the analysis of the preceding sections, consider the following example:



p_1 = Initial pressure = 35 psig

p_2 = Ambient pressure = 14.7 psia

v_1 = Cylindrical tank volume = 50,000 ft^3

r_i = Tank radius = 16.5 ft

Distance between tank bottom and ground = 6 ft

From Figure 1, when ignoring the work done against the atmosphere, w_{TNT} = 50 x 3.7 = 185 lb TNT. When subtracting the work done against the atmosphere, w_{TNT} = 50 x 1.6 = 80 lb TNT.

In Figure 2 an attempt is made at extrapolating the shock tube analogy data for an air burst with the expected ground overpressures in an analogous manner to that of both the conventional TNT charge and nuclear blast approaches. For the "near-in" conditions, unreflected cylindrical and spherical shock overpressures are calculated from Equation 10. Here, for the cylindrical shock (Curve a), the initial surface area A_i of the tank is $A_i = 2\pi r_i l$, where r_i = 16.5 ft and in pure cylindrical shocks the length l drops out of the $\frac{A_i}{A_f}$ ratio.

For the equivalent spherical case (Curve c) which is more appropriate for larger distances from the source (i.e., 200 to 300 ft), the equivalent tank radius is approximated to be 23 ft. Thus, for the spherical case $A_i = 4\pi r_i^2$ where r_i = 23 ft.

Since the cylindrical shock is more appropriate for the "near-in" conditions, Curve a is modified by the ground reflection data of Figure 371b of Reference (10) to produce Curve b. For the larger distances from the source, the shock strength reduces from that of a cylindrical incident front to spherical, and again surface reflection must be accommodated. In a manner analogous to the doubled weight approach for TNT, Curve d is constructed by utilizing Equation (10) and by effectively doubling the size of the initial surface area. Thus,

$$\left(\frac{A_i}{A_f}\right)_{\text{hemispherical}} = 2\left(\frac{A_i}{A_f}\right)_{\text{spherical}}$$

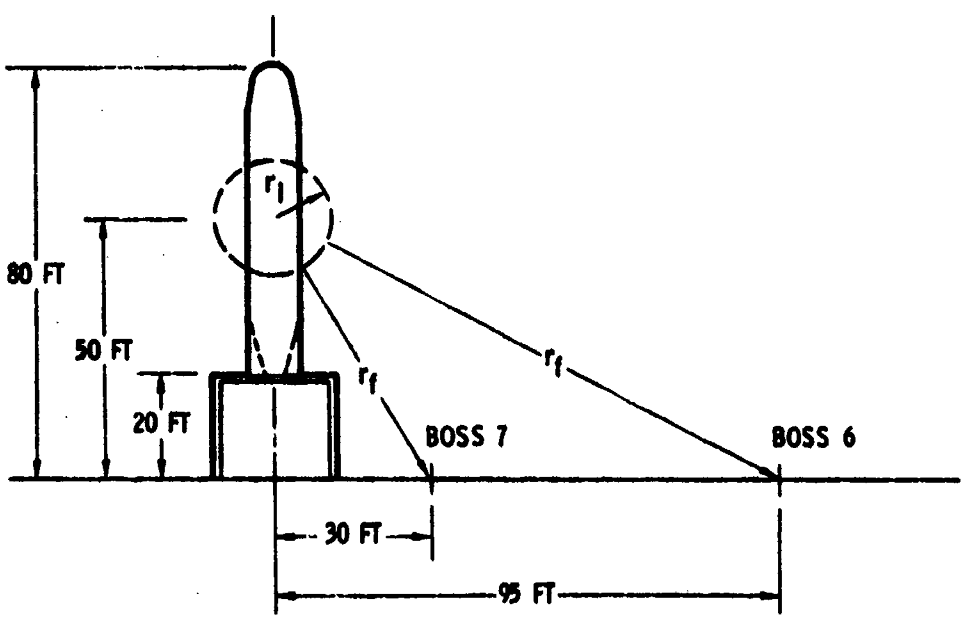
Curve e follows the nuclear explosive approach and is constructed simply by multiplying the unreflected overpressure of Curve c by 2. A transition from the reflected cylindrical shock of Curve b to the reflected spherical shock of Curve e is indicated only because both curves are based on the nuclear blast approach and are thus consistent with each other. Even here, in the construction of Curve e, something must be said about the use of Mach stem values for the pressurized gas case because the region in which the reflected wave travels is lower in temperature than that in which the incident wave travels. This is because of the adiabatic expansion of the compressed gas which was initially at ambient temperature. This is somewhat ambiguous

because at the ground surface where the incident and reflected waves ideally join, the incident wave has done adiabatic compression work on the ambient and thus within the positive pulse region behind the incident shock, the temperature is above ambient and the reflected wave is initially travelling in the overheated region which travels with the incident shock. Thus, conditions are favorable for coalescense of the two shocks locally. The height of this type Mach stem should increase at a much smaller rate than that of the high yield explosion, however.

Finally, Curves f and g are plotted to show the plot of overpressure vs distance as predicted by the 185 and 80 lb TNT equivalencies previously. While the other curves at large distances do not differ by large absolute values, they obviously over-predict the overpressure because atmospheric dissipation is ignored.

VERTICAL TANK ANALYSIS COMPARISON WITH EXPERIMENTAL DATA

A destructive test is reported in Reference 2 on a nitrogen pressurized Atlas tank. The test was set up as follows:



Oxidizer tank volume = 2500 ft^3
Fuel tank volume = 1550 ft^3
Total 4050 ft^3

p_1 = Initial pressure = 35 psig (both tanks)

p_2 = Ambient pressure = 14.7 psia

Based on four pressure measurements at Boss 7 and one measurement at Boss 6, the peak "face on" pressures detected were approximately 1.4 psig at Boss 7 and 0.81 psig at Boss 6. (It should be noted that while the pressure pickup instrumentation was intended to register face-on pressures, damage to guinea pigs exposed to the blast caused the author to speculate that the ground level blast gages were indicating more of a side-on pressure than a face-on pressure.)

With the test conditions stipulated, when ignoring the work performed on the atmosphere, from Figure 1, $w_{TNT} = 4.05 \times 3.7 = 15$ lb TNT. When subtracting the atmospheric work, $w_{TNT} = 4.05 \times 1.6 = 6.5$ lb TNT. This is represented by Curves a and b of Figure 3.

In order to apply a spherical shock analogy, the equivalent initial spherical radius was found to be 9.9 ft. Again applying Equation 10, the unreflected spherical shock data are presented as Curve c and the reflected shock data are given as Curve d.

From these curves, it is seen that the TNT equivalency when subtracting atmospheric work coincides with the closest measured data but is unconservative at the farther point where the TNT equivalency which ignores atmospheric work is more suitable. Interestingly, the unreflected spherical shock analogy yielded a reasonable correlation while the reflected shock values were considerably too large. This can perhaps be attributed to the cylindrical shape of the vehicle which is directional laterally so that the shock strength was smaller at the near-in blast measurement positions than would be from a spherical source, and by partial shielding from the test stand.

With this in mind, a spherical shock emanating from the lower bulkhead region was considered based on the 5-foot tank radius. The center of the blast wave was taken as 20 feet above ground, the approximate height of the tank bottom. The unreflected and reflected spherical shock pressures are presented as Curves e and f. Substantially better agreement is found between the shock analogy prediction and the test data.

In order to emphasize the influence on the selection of the assumed center of blast on the TNT equivalency prediction, the three figure symbols of Figure 3 indicated identical pressure measurements based on the three reference points indicated. For near-in conditions the effect is pronounced while at the Boss 6 location, the effect is small.

CONCLUSIONS AND RECOMMENDATIONS

From the results of the Atlas destruction test, it is concluded that pending additional data the TNT equivalency based on total potential energy (ignoring work on the atmosphere) is the most suitable equivalency for application.

For near-in applications, as a second precaution it is recommended that the appropriate shock tube analogy be applied, especially when the tank size is large compared to structures of concern. Here the impingement angle with the structure and with the ground on the sides of the structure should be considered.

Since only one suitable test (large volume-moderate pressure) has been reported in the literature (to the author's knowledge), additional scaled tests and correlations should be pursued. Also, since nondestructive pneumatic tests are presently underway at many booster stage manufacturers and government agencies, it is recommended that blast gages be installed as a matter of course in order to increase the background of measured data upon inadvertent tank rupture.

ACKNOWLEDGMENT

Thanks is expressed to Mr. A. Africano for technical discussions and background data supplied for this study.

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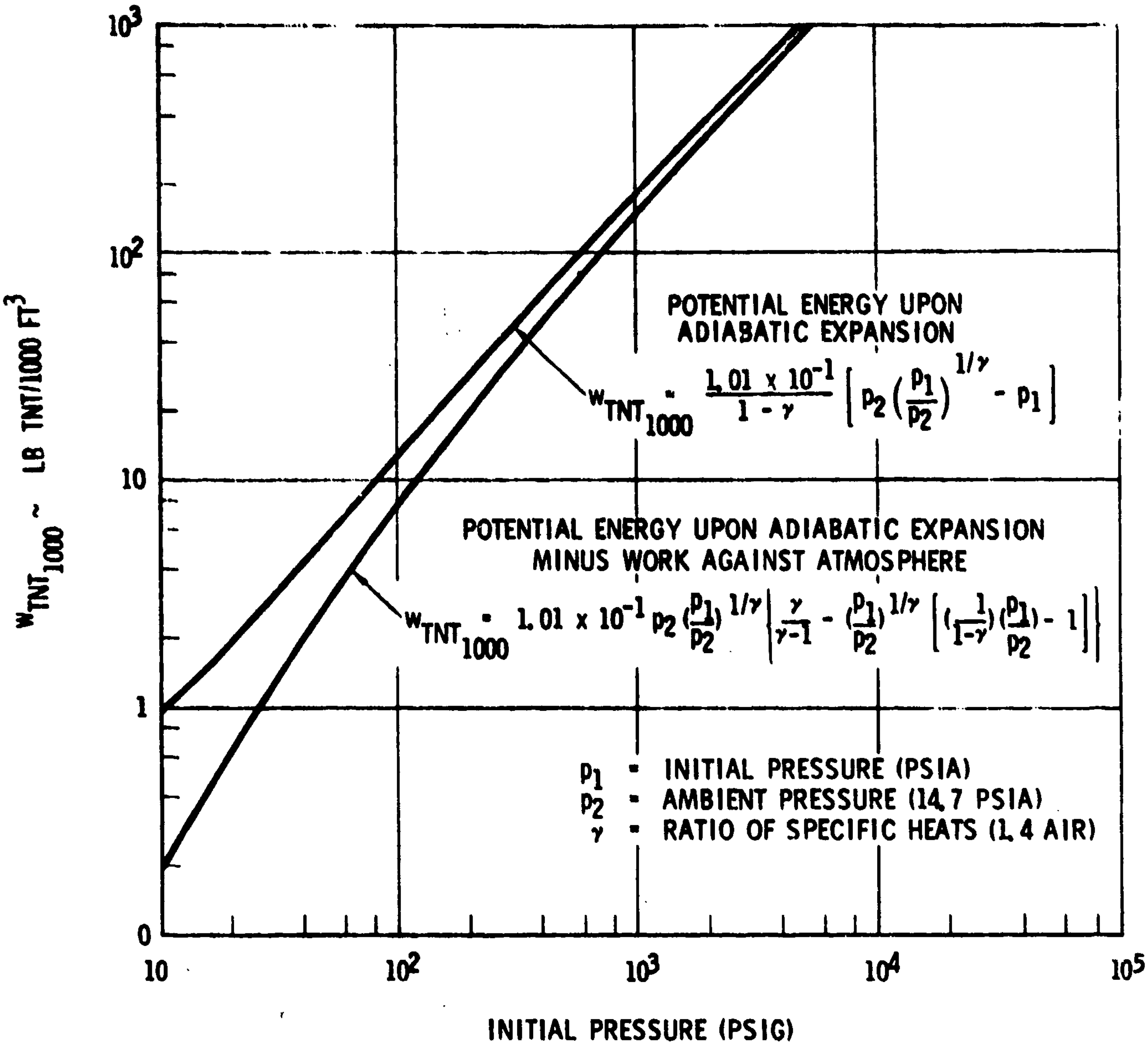

Figure 1. Comparison of TNT Equivalences Based on Adiabatic Expansion With and Without Work Against Atmosphere

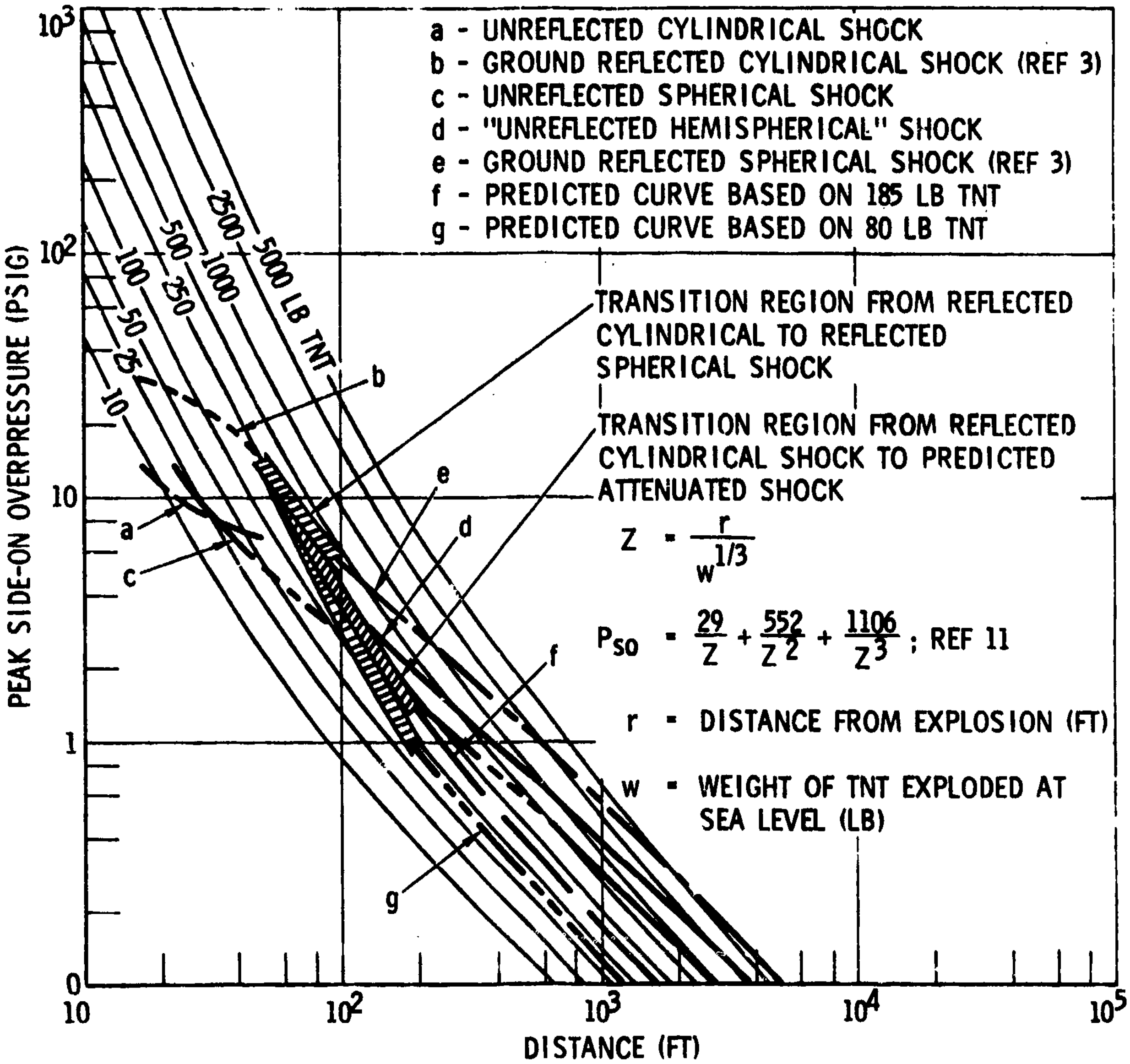

Figure 2. Peak Side-On Ground Blast Pressure as a Function of Distance and Weight of Explosive; Variable Area Shock Tube Analogy Results Superimposed

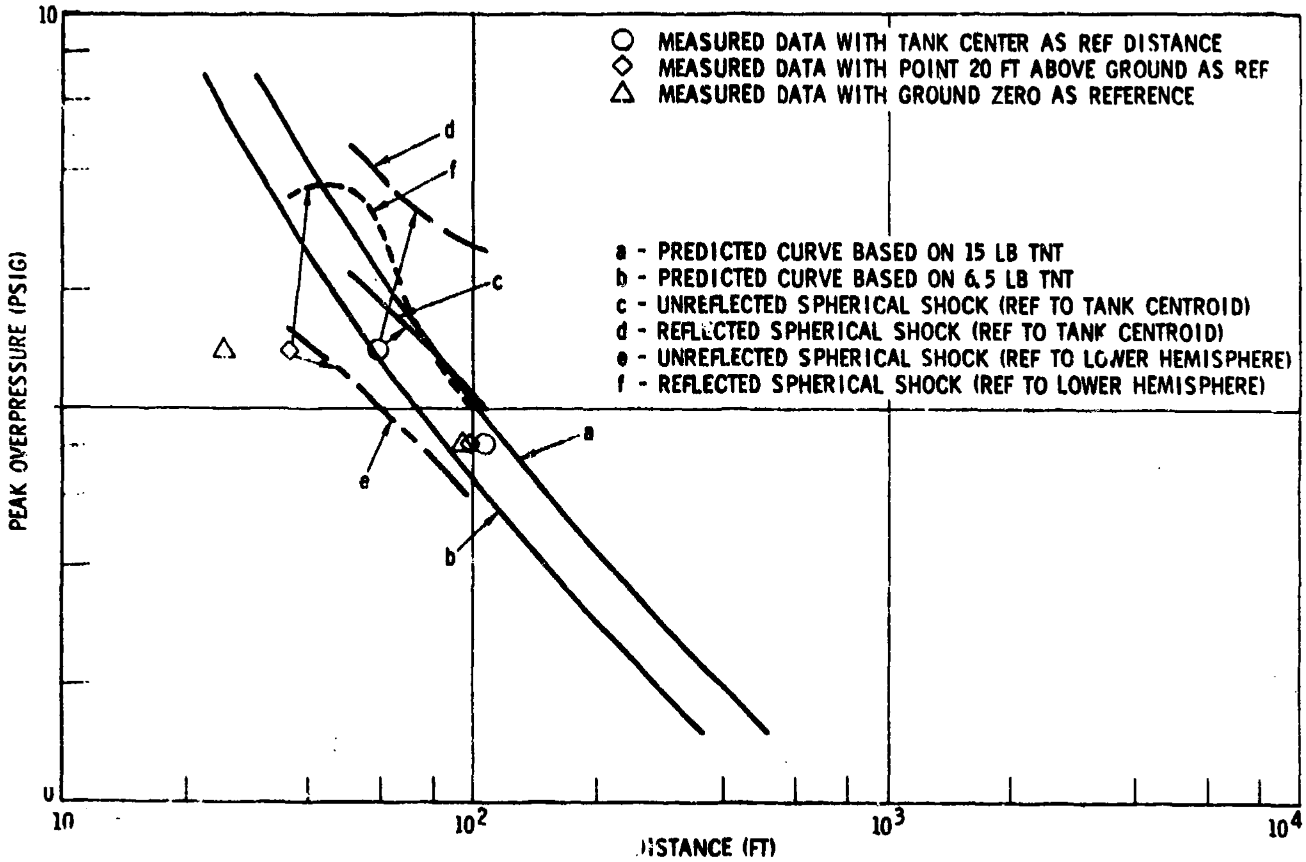

Figure 3. Peak Blast Pressures Vs Distance for Atlas Destruction Test

STARTLE REACTIONS OF PEOPLE TO SONIC BOOMS

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INTRODUCTION

Any sudden, intense sound usually serves as a warning signal of danger to man and animals, particularly if it is unexpected. Such a stimulus elicits in man both voluntary and involuntary responses on the part of various muscles and organs in the body that could perhaps, under certain conditions, indirectly cause harm to some object or himself. There is some concern expressed that involuntary startle movements by people exposed to sonic booms from SSTs could, on occasion, result in some such harmful consequences, particularly when engaged in work requiring delicate muscular coordination.

There have been a few research studies and observations made under real-life conditions of the reaction of people to sonic booms and to other sounds that might be expected to effect people somewhat the same way as do sonic booms. In this paper we will briefly review these studies and observations and attempt to interpret the results with respect to possible adverse psychological and physiological startle reactions to sonic booms.

Audibility of Booms

Before discussing startle reactions it is perhaps appropriate to consider some of the relations between the physical characteristics of sonic booms, or "N"-waves as they are often called, and the nature of the hearing process. We all know that outdoors booms are heard as a sudden sharp crack, but that some booms sound differently than others. The physical factors that appear to be the most significant are: 1) the rise time, and 2) the peak intensity of the boom. The duration of the N-wave (the time from the beginning to the end) has little effect on the total loudness, but does help determine whether an N-wave will be heard as a single or double boom; if the N-wave is of shorter duration than 50-100 msec, it will always be heard as one "crack," but if it has a longer duration the listener may or may not perceive two cracks appearing in rapid succession. Just why, when

hearing a given boom, some people hear two cracks and others hear only one crack--a commonly reported disagreement among observers--is still something of a mystery. It has been suggested that auditory fatigue from the first, or positive, impulse of the N-wave might persist long enough in some ears to prevent or reduce the hearing of the second, or negative, impulse.

Loudness

Several studies of the loudness of acoustic impulses having different rise times, amplitudes, and total durations have been performed at the Institute of Sound and Vibration Research at the University of Southampton, England, and the Lockheed-California Company. In these investigations the experimenters systematically varied the waveform of the impulses presented to listeners wearing special earphones (at the University of Southampton) and to listeners in a special booth via loudspeakers (at the Lockheed Company).

Perhaps the most significant outcome from these studies was the demonstration of Zepler and Harel, and later of the Lockheed-California Company, that the loudness of an N-wave is highly correlated with its spectrum. The spectrum of an aperiodic wave or impulse is, of course, to a large extent influenced by its initial rise time--the time that elapses from when the pressure wave leaves ambient level until it reaches its peak level. Zepler and Harel calculated the power spectrum of N-waves used in the loudness studies at the University of Southampton and then weighted this spectrum according to the 80-phon equal-loudness contour of Robinson and Whittle, extrapolated down to about 40 Hz. Integrating the area under the resulting weighted spectrum gave a calculated measure of loudness. It is seen in Fig. 1 that this calculated loudness agrees very well with the judged loudness of N-waves having different rise times. Inasmuch as the so-called equal-noisiness and equal-loudness contours are parallel at frequencies below 1000 Hz, the method of analysis used by Zepler and Harel applies equally well to perceived noisiness as to perceived loudness.

It has been recognized for many years that the ear behaves as a set of bandpass filters and should, therefore, readily respond to the spectrum of a complex acoustic signal. Applying this notion to sonic booms, as did Zepler and Harel, may at first seem unwarranted inasmuch as the energy in

the sonic boom is largely concentrated in the frequency region usually considered as being subaudible. However, there remains considerable energy in a typical N-wave in the audible frequency range above 20 Hz or so.

Figure 2 shows the energy spectra for sonic booms from three supersonic military aircraft. It would appear from the tracings of the pressure variation of the N-wave, seen in the lower lefthand corner of the figure, that the rise time of the positive portion of the wave is approximately comparable for all three booms but that the durations are radically different, being about 75 msec for the F-104, 175 msec for the B-58, and 300 msec for the XB-70. Of importance for the audibility of these three booms is the fact that the distribution of energy above 20 or 30 cycles is approximately the same for all three booms; the fact that there is much more energy in the frequencies below 10 cycles or so in the boom for the XB-70 than for the other booms is relatively unimportant to how the boom sounds outdoors because the ear is not sensitive to these lower frequencies.

In short, theory and the experiments of Zepler and Harel and others would say that these three booms heard outdoors should be of roughly equal loudness or perceived noisiness inasmuch as they have the same peak overpressure and the same amount of energy in frequencies above 20-30 cycles. Indeed, tests conducted at Edwards Air Force Base, insofar as present data analysis permit, substantiate this conclusion particularly when the booms are heard outdoors. Figure 3 illustrates that the energy in the frequency regions from 20 cycles to 400 cycles is closest to the equal loudness and perceived noisiness frequency contour and therefore probably determines the perceived loudness or noisiness of a sonic boom heard outdoors, and that the energy present at higher and lower frequencies is relatively unimportant.

It should be emphasized, however, that when heard in a house, the sound of the boom may be significantly influenced by the energy in frequencies below 30 cycles because typical house structures tend to resonate and vibrate at these lower frequencies. These vibrations (creaks and rattles in a house) are, of course, a bothersome aspect of sonic boom stimulation.

Laboratory Tests of Startle

So much for the characteristics of the human ear as a receptor of acoustic energy. Of more practical interest for this symposium is the question of psychological and physiological startle effects of sonic booms on people.

It has been generally presumed, largely on the basis of everyday observations, that persons living and working in environments where intense, impulsive sounds are present adapt to such stimuli following repeated exposure to them. Further, it is observed that this adaptation or lack of startle occurs even for irregularly presented sounds--for example, personnel operating on and in the close vicinity of gunnery ranges at army training bases appear to be more or less unaffected by sounds that often have peak overpressures equal to and in excess of the 133 dB (about 2 psf) expected for sonic booms from commercial aircraft.

It is doubtful, although it cannot be proven from existing data, that this adaptation or nonresponsiveness to expected stimuli does not require any effort of the person. Finkle and Poppen and others have shown complete physiological adaptation to very intense sounds that are accepted as part of one's normal environment. On the other hand, some European investigators claim that persons working in foundries and such occupations suffer from circulatory difficulties and have nervous disorders that are attributable to the presence of intense noise. These latter studies, however, cannot be accepted as definitive because the presence of many uncontrolled factors beyond the presence of noise (personnel selection, excessive heat, dirt, etc.) make the interpretation of the results difficult.

Pertinent laboratory studies of adaptation of the startle response to acoustic stimuli have been few. Davis, in 1932, found that the psychogalvanic skin response, usually though to be a measure of startle reaction, rather quickly adapted or stopped responding to repeated short explosive sounds. Davis and Van Liere measured by electrical means muscular tension in the forearm muscles of subjects exposed to gunfire (blank cartridges fired in the laboratory). They found that when the SPL of the gunshots exceeded 90 dB, there was an increase in muscular tension of two kinds:

an "A" response, which occurred within 0.5 sec after the gun fired, and a "B" response, which occurred approximately 1.5 sec after the shot. Adaptation to the "A" response was complete within 5 gunshots, whereas the "B" response did not adapt completely within the 5 gunshots.

In a recent study, Hoffman and Fleshler exposed rats to gunshot-like impulses and measured their startle reactions (amount of movement as measured in an activity cage). They found that the amount of startle was a function of the acoustical environment--in some cases, the general background condition was pulsed noise; in some cases, steady-state noise; and in others, silence. Interpretation of the interactions between these different acoustic backgrounds and the impulsive sounds is an interesting but complicated matter; however, within a given environment, adaptation was found.

Pearsons and Kryter attempted to study the startle response to sonic booms presented via a loudspeaker. Subjects seated individually in the small cubicle were told that they were to participate in the experiment on the relaxing effects of music. The subjects' heart rate was recorded from electrodes attached to their arms. Eleven subjects were used.

The test period was 10 min for each subject, during which time they were presented with a background of musical recordings. Intermittently during that 10-min period, 9 of the subjects were presented with 10 simulated outdoor sonic booms at a peak overpressure of 2.3 lb/ft^2. Two of the subjects served as controls and heard only the music during the test period. Figure 4 shows sample and typical results obtained from the subjects. It is seen in Fig. 4 that a few of the subjects showed an initial increase in heart rate (heart rate was measured over 10-sec intervals) following the first one or two sonic booms, but that, in general, the variations in heart rate were not systematically relatable to the occurrence of the sonic booms. Questionnaires administered to the subjects after the tests sessions indicated that all subjects reported startle to the first few booms even though some of them did not show a change in heart rate.

Nixon and Lukas have recently conducted an experiment in which subjects were sometimes exposed to simulated sonic booms as heard indoors.

Over a four-week period 24 subjects received four one-hour test sessions. During each test session, nine booms were presented at more or less random times. During some of these sessions the subjects were asked to trace with a metal stylus a metal track etched on a glass surface.

Electromyographic recordings were made of the trapezius (neck-shoulder) muscle on the side contralateral to that used by the subject for tracing. The act of tracing alone did not cause more than normal muscle response in the trapezius muscle, but the sonic boom did cause greater muscular activity. This muscular activity, which could be called a "jerk" or startle response, generally became less within the hourly sessions, particularly subsequent to the first session,and definitely lessened over subsequent sessions. These results are shown in Figs. 5 & 6. As will be mentioned later, additional laboratory studies on this problem will be conducted.

Laboratory experiments on adaptation, such as those cited above, are always somewhat suspect because the subjects may behave differently to a sound under experimental conditions than they would to the same sounds in real life. For this reason, one cannot definitely answer from the laboratory investigations made to date the question as to whether people will be startled by sonic booms when these sonic booms become a more or less regular part of their auditory environment. Observations of the behavior of people in some everyday noise environments would suggest that the average person would cease to be startled, at least as measured physiologically, with continued exposure to sonic booms and most of the results of laboratory tests would not run counter to this conclusion.

Startle to Sonic Boom in Real Life

For a six-month period in 1964, supersonic military aircraft--primarily F-104--were flown over Oklahoma City at the rate of about seven flights per day. The average peak overpressure was approximately 1.4 psf which is somewhat less than that predicted for SSTs.

Table 1 gives the types of interference or disturbance reported by people living in Oklahoma City. We see in this table that startle was a significant and major source of complaint. What is meant by startle varies, of course, from person to person. Perhaps in the present context, of most

significance would be the type of startle that causes a muscular response in the person such that the person's hands move perceptably or his sense of balance is affected. This type of involuntary muscular response is, of course, felt when one is startled by a stimulus, be it auditory, visual, tactile, etc. But, how far does a person's hands move, how much does he "jump"? To the best of my knowledge there have been no experiments which provide answers to this question, such as how many centimeters, on the average, a person's hand moves when he is startled. We are undertaking experiments at the present time at Stanford Research Institute in an attempt to measure, in a quantitative way, such movement.

At the present time we must rely on anecdotal information to describe the probable effects of sonic booms on this type of startle. To that end, let me contribute the following notes and comments:

1. Notes of NASA engineer when in hospital at Edwards Air Force Base:

    0852 - 1 sharp boom; puffed curtains; very noticeable, but not annoying.

    0912 - Sharp double boom. Very glad I was not being operated on at the time. Curtains puffed, glass rattled on bedside tray. Annoying.

    0929 - Dull single boom. Note: Dull booms more annoying to me as they seem to move things around.

    0938 - Distant double boom; no reaction.

    1042 - Dull thump; moved bed, etc.

    Note: Booms do not seem to bother hospital staff when on duty, but they do at home (common complaint: glass movement).

2. It was noted that engineers at Edwards for a month or so, as well as residents at the base, were usually not visibly startled by the booms, but that occasionally they would "jump" to a particularly loud or unexpected one.

3. A barber in London cut a customer's ear with a scissors when startled by a boom, and a man in Chicago claimed he punctured his

eardrum when startled by a boom while cleaning his ear, etc.

4. But considering all the people that have been exposed to sonic booms and all the booms they have been exposed to, it is perhaps surprising that there have been such few claims of injuries resulting from muscular startle reactions to sonic booms. On the other hand, a startle reaction would be a rather useless thing if it lead to bodily harm, even if indirectly; the purpose of a startle reaction is presumably to alert one to and make one ready for a danger.

Intuitively, I believe that the more delicate the motor task a person is engaged in, the least likely he is to be startled by a sonic boom, and if he is, the least likely he is to make a movement that would be hazardous. It is the relaxed person, I would guess, that is the most off-guard and susceptible to startle to sonic booms.

Conclusions

1. Both laboratory and real-life observations attest to the ability of the human to adapt physiologically with repeated exposure to sonic booms.

2. It appears that the startle response of people to sonic booms is psychologically bothersome, but seldom causes muscular movements that endanger the performance of even delicate motor tasks.

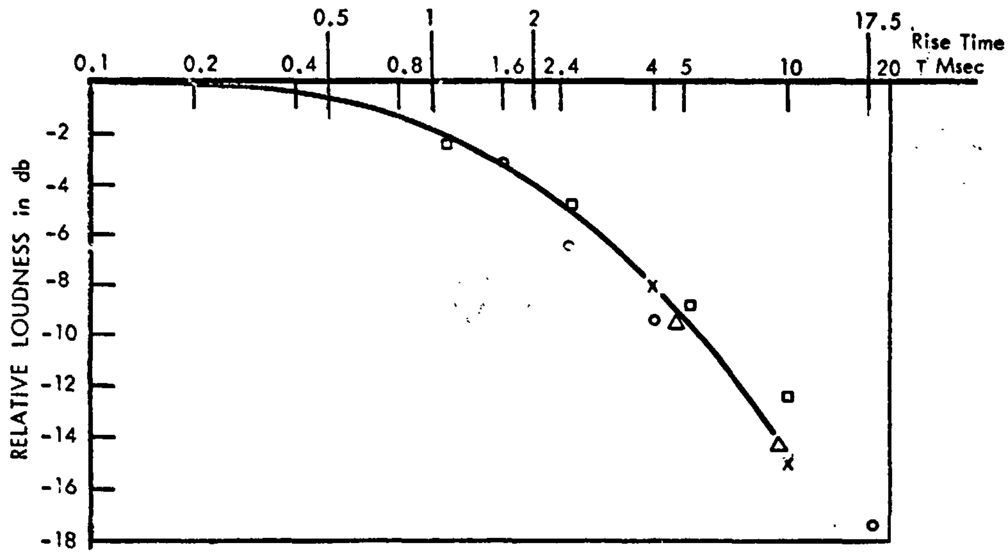

Fig. 1. Relative loudness of "N" waves as a function of their rise time, keeping peak amplitude constant. It is seen that loudness predicted on the basis of loudness-weighted spectra agrees with results of judgment tests.—:Predicted loudness. X, O, □, △: Results. [From Zepler and Harel.[9]]

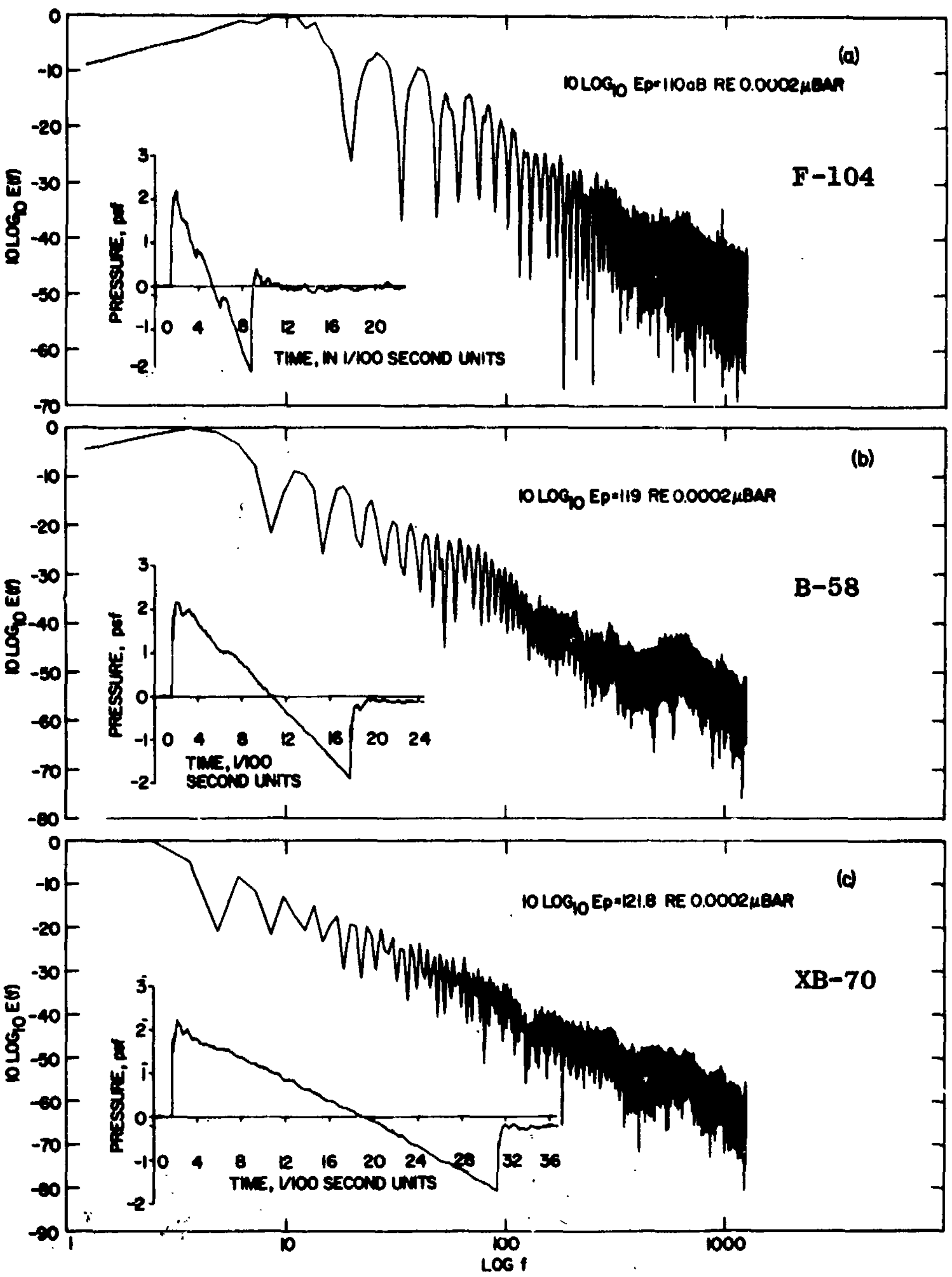

FIG. 2 PRESSURE-TIME AND E(f) PLOTS FOR THREE AIRCRAFT; F-104, B-58, AND XB-70

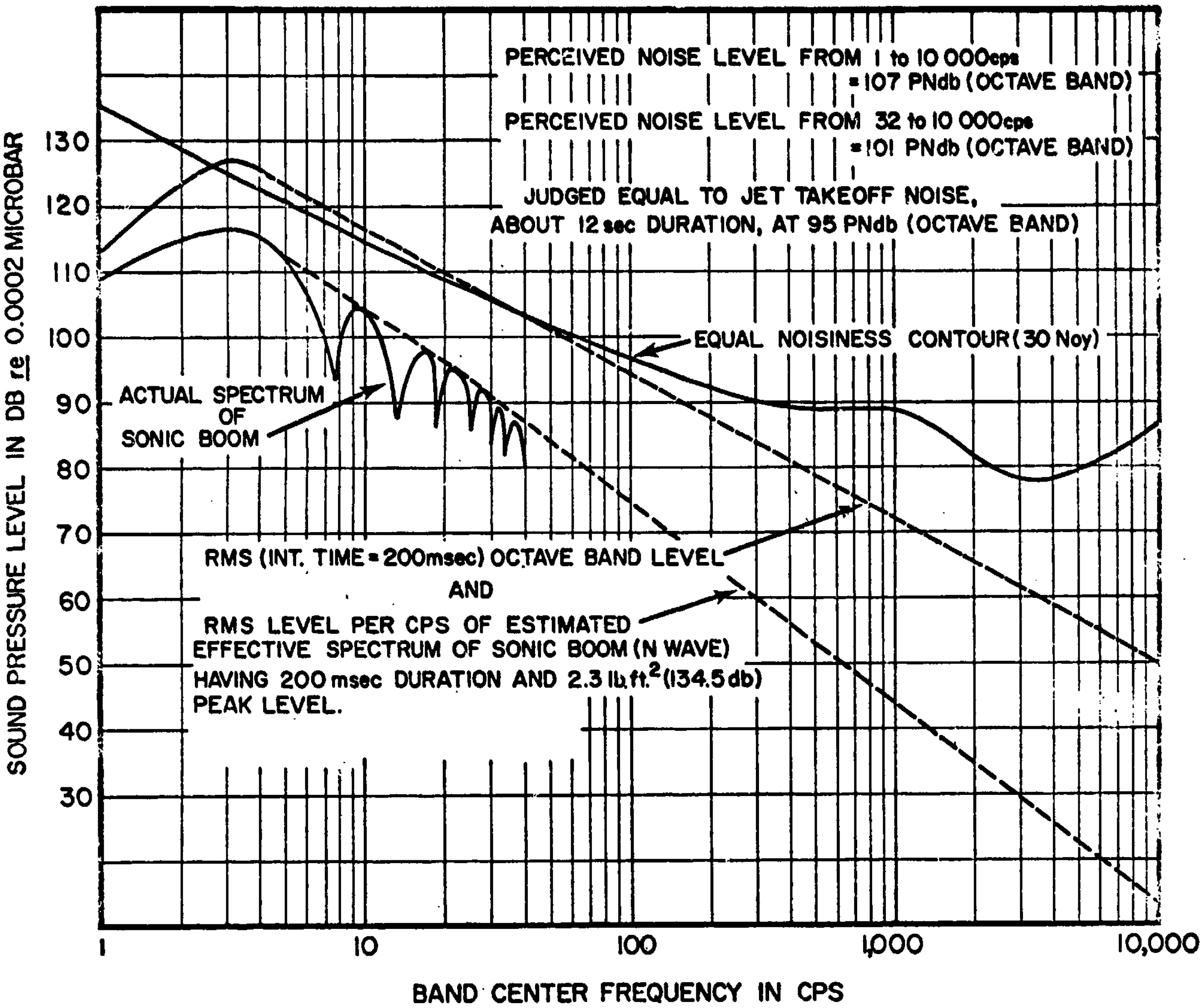

FIG. 3. Relation between spectrum level and octave-band spectrum of sonic-boom and equal-noisiness contour. PNdB for sonic boom exceeds peak PNdB value of subsonic-jet-aircraft takeoff noise judged to be equal in noisiness to the sonic boom.

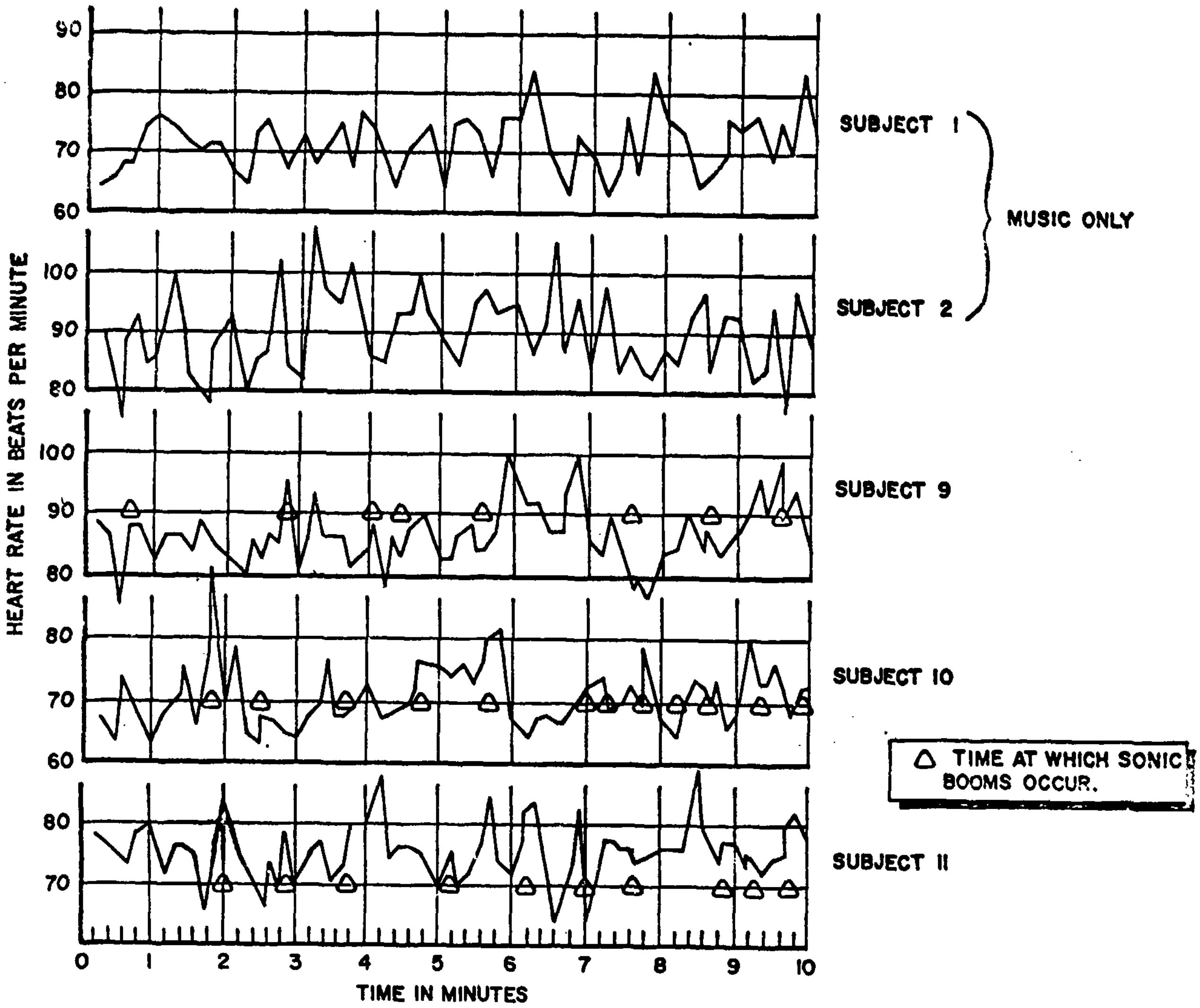

FIG. 4. Variation in heart rate (average of 10-sec intervals) for subjects listening to soft, relaxing music, and, for some subjects, occasional, unexpected sonic booms. [After Pearsons and Kryter.[9]]

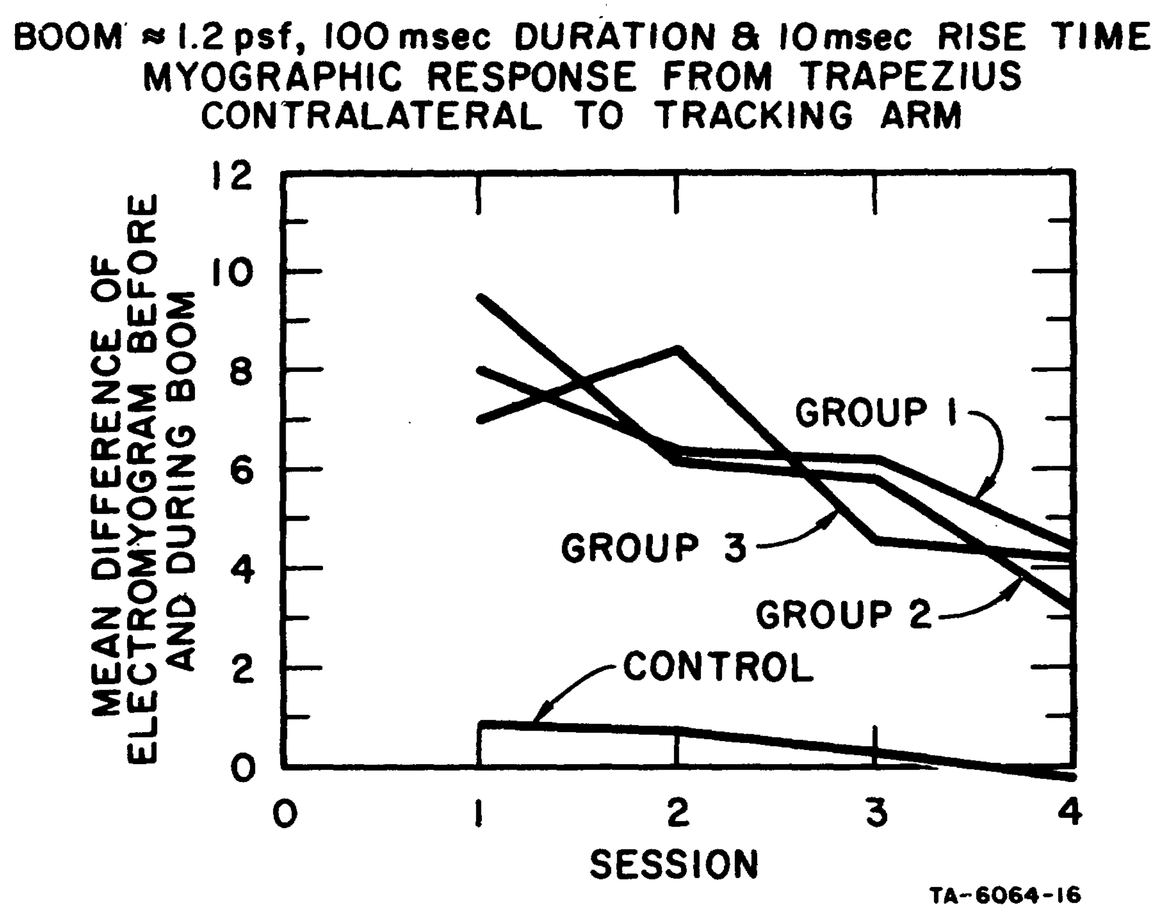

FIG. 5 MEAN MUSCULAR "STARTLE" RESPONSE TO BOOMS, NORMALIZED FOR EACH SUBJECT AND INTEGRATED OVER 1/2 sec, AS A FUNCTION OF SESSION.

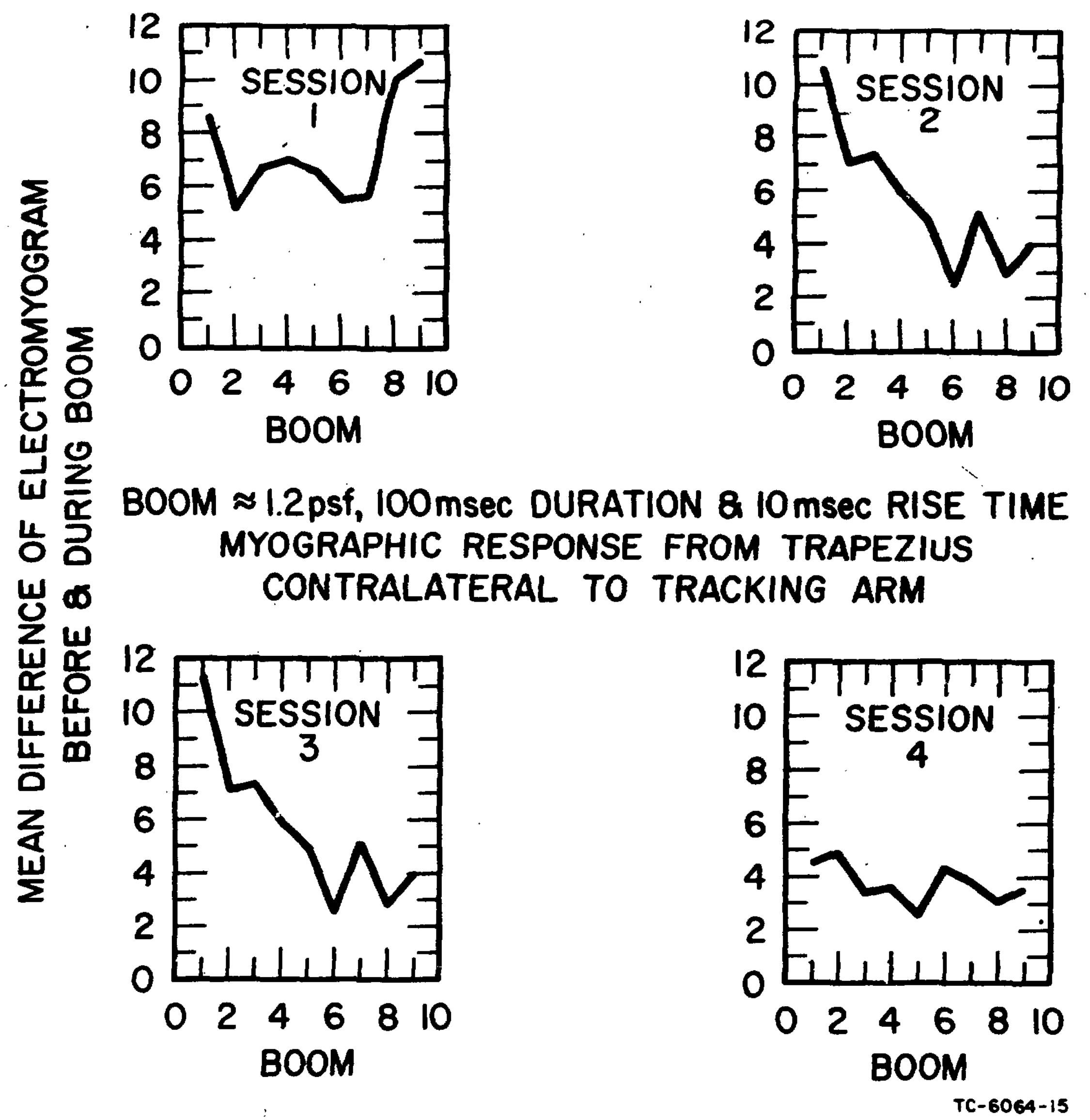

FIG. 6 MEAN MUSCULAR "STARTLE" RESPONSE TO BOOMS, NORMALIZED FOR EACH SUBJECT & INTEGRATED OVER 1/2 sec, AS A FUNCTION SESSION & NUMBER OF STIMULATIONS.

Table 1

PERCENTS OF RESPONDENTS ANNOYED BY
VARIOUS SONIC BOOM INTERFERENCES

Type of Interference	Oklahoma City
House shaking-rattles	54%
Startle	28
Sleep interruption	14
Rest interruption	14
Conversation interruption	10
Radio-TV interruption	6

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SONIC BOOM - ITS SIGNATURE CHARACTERISTICS

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SUMMARY

This paper presents the origin of the sonic boom, some of the characteristics of the boom, and describes some of the factors which influence the boom. The three main factors may be classified as aircraft configuration, aircraft operating condition, and observer environment.

Changes in aircraft configuration are shown to have a rather large influence on the boom signature; relatively small geometric changes can have large effects. Of the operating characteristics, it is shown that increasing the altitude has a very large effect in reducing the maximum boom overpressure, but acceleration and maneuvering can cause booms of high magnitude in local areas. The weather environment is also shown by actual measurements to cause large perturbations on the nominal boom signature.

INTRODUCTION

Not too many years ago many people thought it impossible to "crash the sonic barrier," that is, to propel an aircraft faster than the speed of sound. This belief prevailed in spite of the fact that our ordnance people for many years had been producing guns which ejected projectiles at supersonic speeds.

Manned supersonic speeds are now commonplace; fighters and bombers regularly exceed the speed of sound, the B-70 for instance approaching three times the speed of sound or around 2000 mph, and the supersonic transport is now on the drawing board. The X-15 approaches a Mach number of 7. The pilots of these craft do not experience any extraordinary effects as they exceed the speed of sound, but unfortunately we poor earthlings experience on the ground a rather dramatic and widespread effect (figure 1), termed the sonic boom (in England it is termed the sonic bang).

The purpose of this paper is to present the origin of the sonic boom, some of the characteristics of the boom, and then to describe some of the factors which influence the boom. The three main factors may be classified as aircraft configuration, operating condition, and environment.

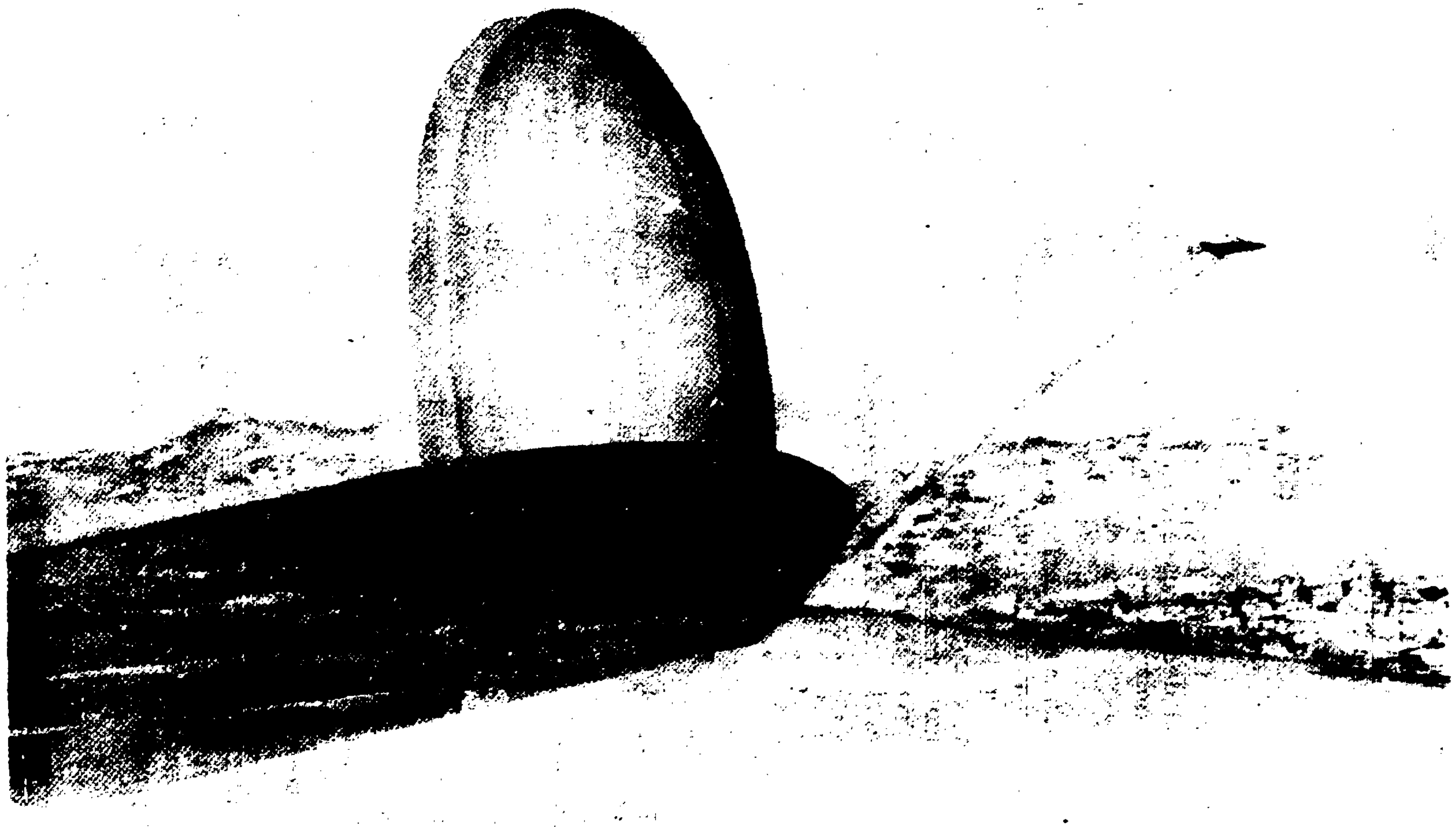

Figure 1.- Sonic-boom pattern.

NATURE OF SONIC BOOM

The sonic boom is, quite succinctly, the result of shock waves created by a body moving at speeds greater than the speed of sound. Let us examine the form of the propagation waves for the case of (1) a stationary disturbance, (2) a disturbance moving at a speed below the speed of sound, and (3) a disturbance moving at a speed above the speed of sound (figure 2). For the stationary case (or case of an explosion), the disturbance radiates in a symmetrical pattern. For the disturbance moving at speeds below the velocity of sound, the circles will tend to bunch up on the flight direction axis; consequently, the air particles do not receive the signal that an object is approaching quite as soon and, hence, we obtain what has been termed the compressibility effect. This usually results in higher drag as the speed increases until we reach sonic speed where all the circles become tangent at the leading edge, and we experience very high drag. For the supersonic moving disturbance, no warning at all is given to the particles ahead of the line of flight; consequently, we obtain a severe discontinuity which results in a shock wave which is located at the envelope of the circles of disturbance. The pressure jump at this discontinuity is termed the overpressure and denoted by Δp.

Now, what does this distribution of Δp look like for a real airplane? On figure 3 is shown the measured pressure signature for a B-70, flying at $M = 1.5$ at an altitude of 37,000 ft. Four signatures are shown: at 2000 ft. above, 2000 ft. below, 5000 ft. below, and a ground signature. The surprising element about the boom is its persistency for such long distances from an aircraft. The slant range may be as long as 30-40 miles. The signature shape near the airplane is rather complex, because we obtain a shock whenever we have an abrupt increase in the cross-section area of aircraft, such the wing, cockpit, engine, etc. Hence, the near signature shape is highly dependent on the detailed shape and flight altitude of the aircraft. As we move away from the aircraft to 5000 ft. below, the relative position of these shocks changes and these interior shocks tend to coalesce, and the detailed signature becomes simpler in shape, as shown by the signature on the ground. If we were to extend these shock waves further, we would probably obtain a typical N-wave, or far-field signature, shown on the upper right of the figure. This shock pattern then sweeps along the ground at the speed of the airplane, so that any stationary observer on the ground receives a time-varying pressure signal, and many times one can hear two distinct booms, one corresponding to the front shock and one corresponding to the rear closure shock.

With regard to the lateral spread of the boom, this is dependent to a great extent on altitude. To graphically illustrate the lateral spread, the measured and calculated lateral spread for the B-70 aircraft is shown for two altitudes on figure 4, where Δp is plotted against distance. Note that the magnitude of the overpressure at the extremities of the distribution is about one-half that directly under the aircraft. Secondly, there is a definite cutoff lateral distance; for 37,000 ft. altitude the width is about 35 miles, and for 60,000 ft. altitude it is about 60 miles.

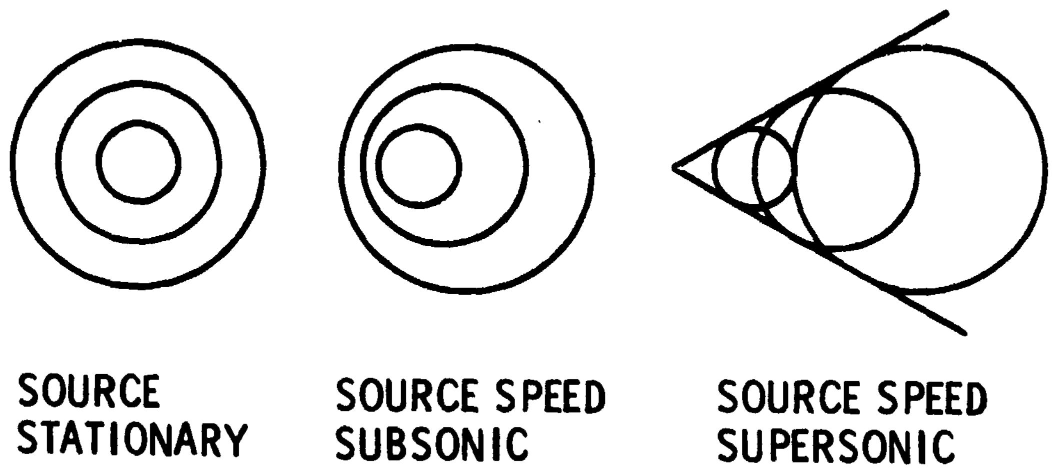

Figure 2.- Wave propagation from a moving source.

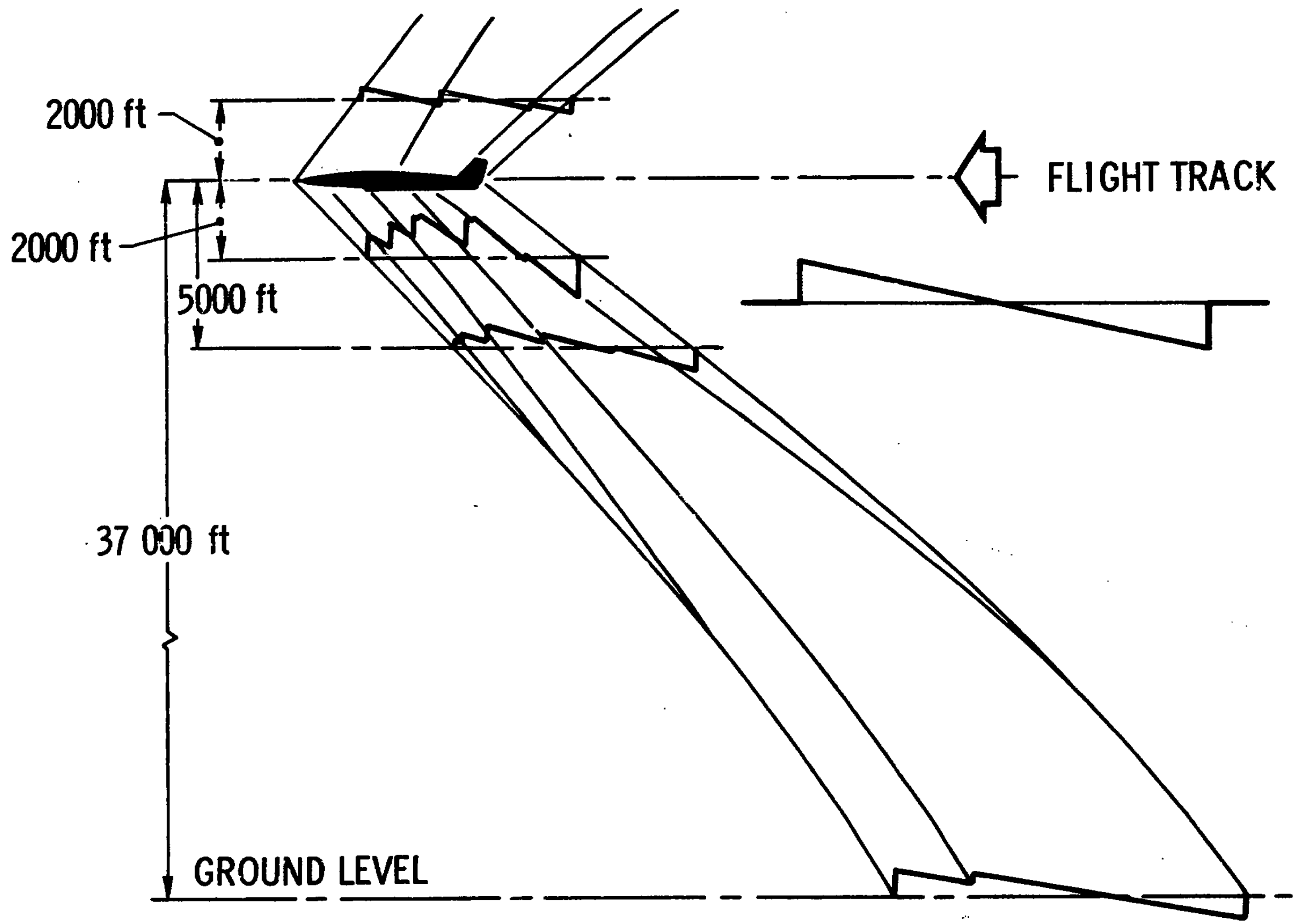

Figure 3.- Schematic diagram showing the signatures measured in close proximity to the XB-70 aircraft in flight compared to a ground signature for the same flight conditions.

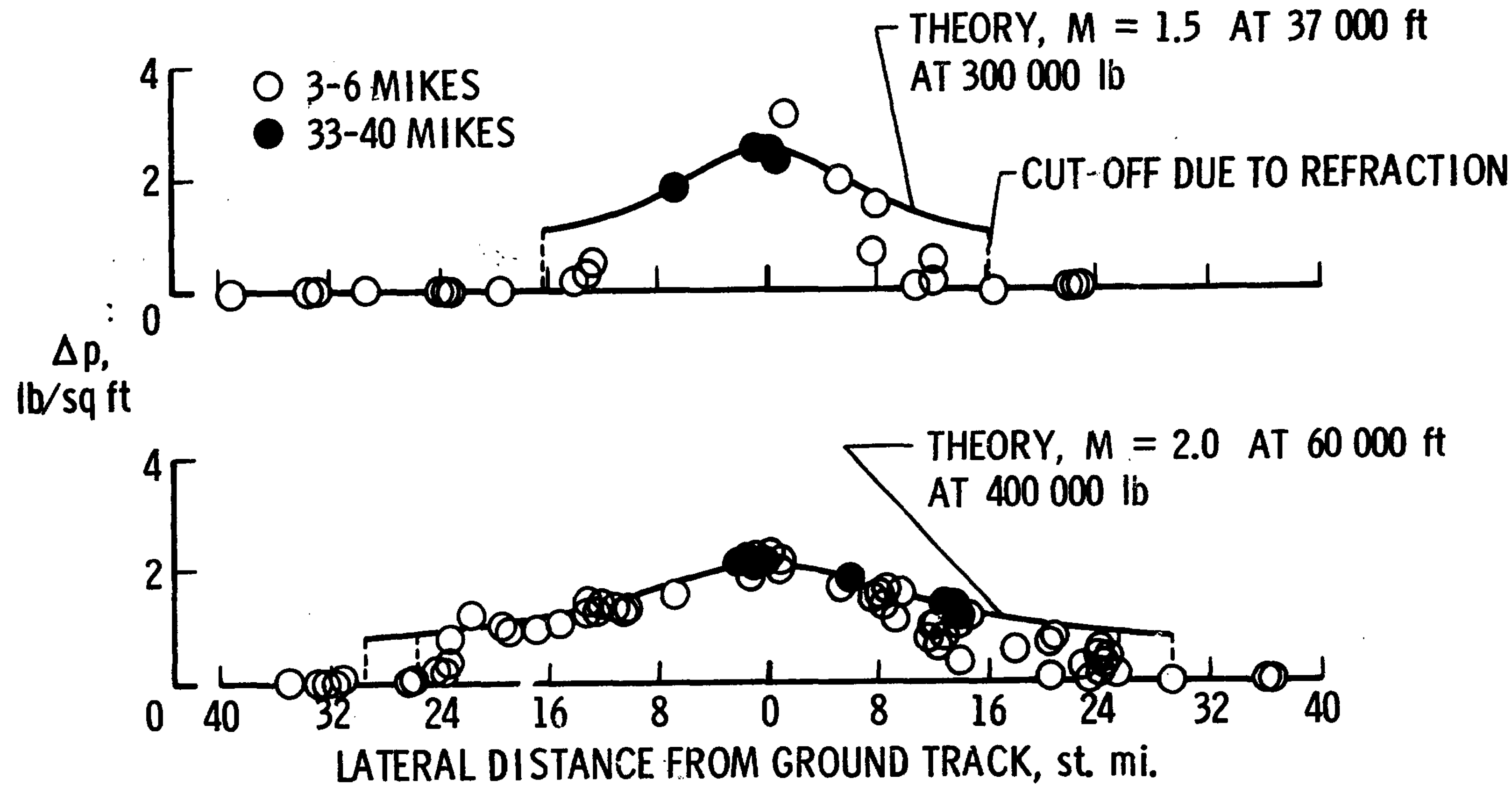

Figure 4.- Sonic-boom overpressures for the XB-70 airplane as a function of lateral distance for two different flight conditions.

The actual ground pressure generated by military aircraft flying in, let us say, routine flight conditions may vary from two to six pounds per square foot, and it must be emphasized that the units are pounds per square foot (figure 5). The question arose as to whether aircraft could be used for tactical purposes in creating booms sufficient to cause damage to military equipment. In this program (in cooperation with the Air Force) we obtained a number of rather extreme overpressures. The next figure (figure 6) illustrates one of these signatures produced by a small fighter type aircraft, and also gives a comparison with some explosive time histories. The sonic boom pressure signature shown is for a small fighter flying at 100 ft. altitude at about $M = 1.2$, which created an overpressure of 120 lbs/ft. We would obtain the characteristic N-wave with a very short period. A TNT explosive charge of 500 lbs. would provide the same pressure at about 400 ft. distance, while a 20 kiloton nuclear explosion would provide a Δp of 120 lbs/ft^2 at a distance of about 17,000 ft. As you know, for explosive type of pressure waves we do not obtain the second shock wave.

The duration of the sonic boom signature will vary for a fighter type aircraft of about 0.05 second, to as much as 0.4 second for a large supersonic transport. The length of the boom will vary with aircraft size and altitude, ranging from 50 ft. for a fighter close to the ground to 800-900 ft. for a large transport flying at high altitude.

FACTORS WHICH INFLUENCE THE SONIC BOOM

There are numerous factors which influence the sonic boom, and we may divide these into three categories, as follows:

I Airplane Configuration
- Size
- Shape
- Weight

II Operating Conditions
- Flight speed
- Altitude
- Acceleration (maneuvers)

III Environment
- Atmospheric winds/turbulence
- Atmospheric temperature and pressure variations
- Terrain features

I Airplane Configuration

With regard to aircraft configuration, the sonic boom signature is highly dependent on the shape and weight of the aircraft. In the design of military aircraft, the boom problem is usually of no consideration, but for commercial aircraft, such as the SST, the reduction of the boom level is of vital economic concern for, as a matter of fact, the whole success of the SST might well

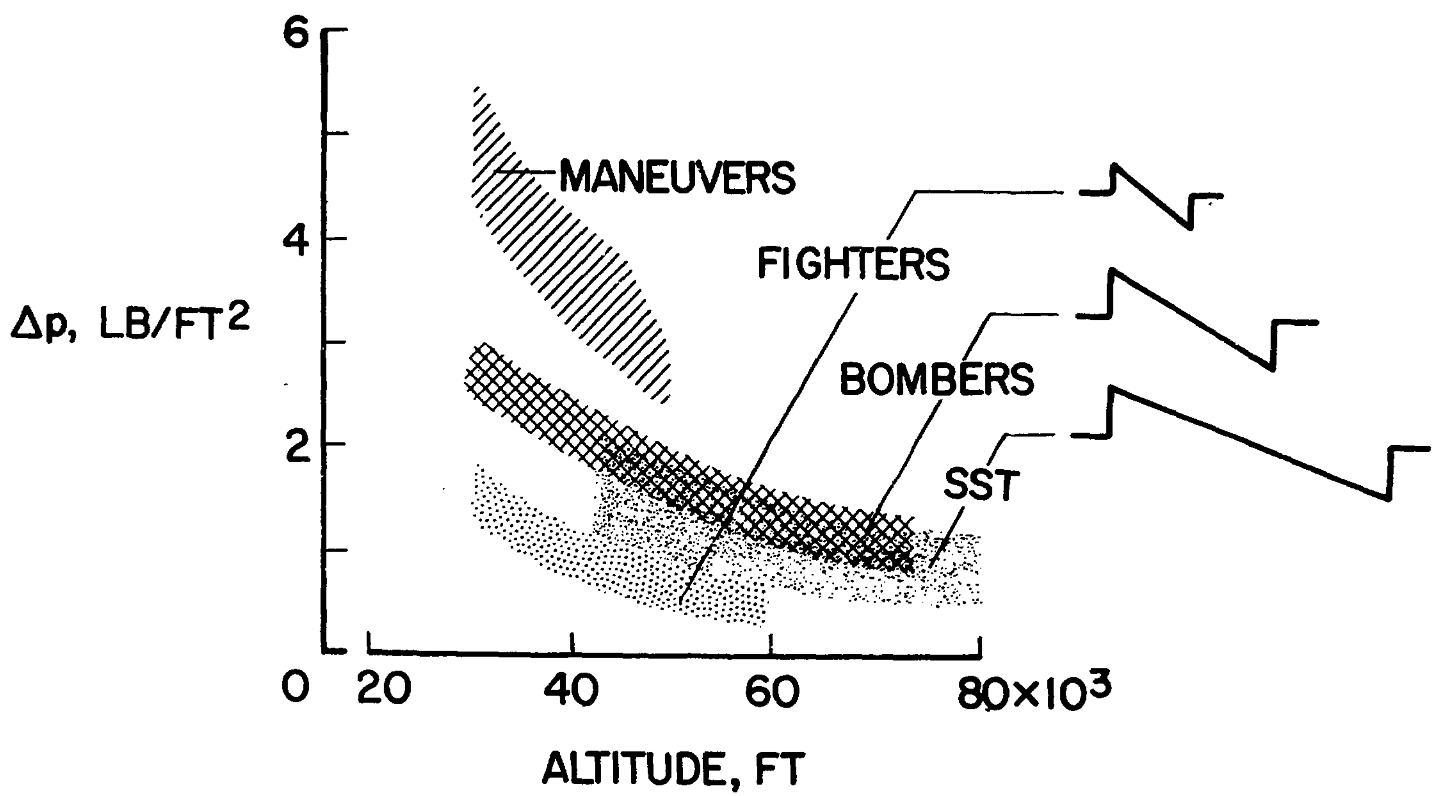

Figure 5.- Sonic-boom overpressures as a function of altitude for three different aircraft.

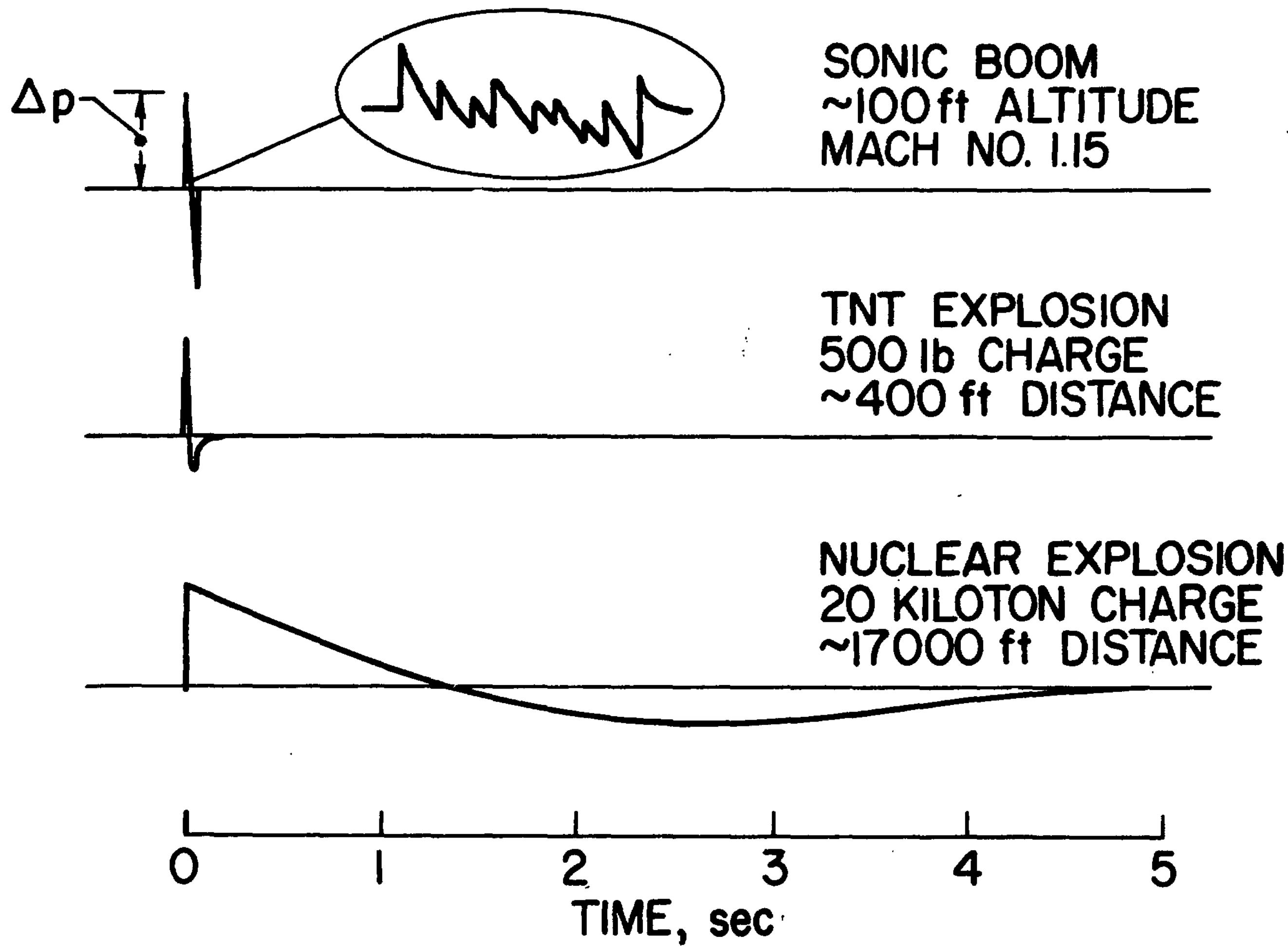

Figure 6.- Shock-wave time histories for 120 lb/ft^2 overpressure.

depend on the reduction of the boom to an acceptable value for land operation. For over-water flight, this is of less concern.

To illustrate the effect of size and shape on the boom, the overpressure Δp is plotted against fineness ratio (fuselage length over diameter), and also against length l on figure 7. On the left, we note that the Δp for the example is reduced by about one-half as the length over diameter ratio is doubled. Thus, we desire slender vehicles for minimum sonic boom. On the right side of the figure we have held the l/d constant and looked at the length effect. For this case, the overpressure doubles as the length increases from 100 ft. to 300 ft.

For a final figure on the configuration effect, the influence of a relatively small variation in cross-sectional shape is illustrated on figure 8. Here, we show results on a large delta-wing aircraft. The solid lines on the three figures represent the original shape, the area ratio, and the shock strength. Referring to the top of the figure, if the external shape is changed as indicated by the dashed lines, the area ratio is smoothed (middle figure), and the final calculated change in the overpressure Δp is shown on the bottom of the figure. Note that the peaked pressure distribution (of the original shape) has been lowered by cutting off the top of the pressure distribution, and it becomes flat, as shown by the dashed lines, a reduction in the front shock by about 30 percent at this particular Mach number.

II Operating Conditions

The significant operating conditions are flight speed or Mach number, altitude, and acceleration. On figure 9 are shown two of these effects; the overpressure Δp is plotted against altitude on the upper left and against Mach number on the upper right. Both of these figures are significant. First, the effect of altitude is very significant. For this particular case, we find a factor of 6 change in Δp from an altitude of 60,000 ft. to about 15,000 ft. Thus, flying at high altitudes is an excellent way to minimize the presure jump, Δp. On the right is shown the influence of Mach number, and we find a very surprising lack of dependence of Δp on Mach number for the curve for values slightly above $M = 1.4$ is nearly flat.

Up to this point, the results of straight, level, and steady flight have been presented. On the other hand, when an airplane accelerates, either by a change in speed or by a maneuver, some very interesting and complicated shock patterns result, and in most of the cases a higher Δp may be obtained, but it is usually localized to a small area on the ground.

To illustrate this acceleration effect, let us examine figure 10. At the left of figure 10 the lateral spread pattern on the ground for an aircraft in steady flight is shown. The projections of the ray paths on the ground, as represented by the fine lines, are generally parallel to each other; and the shock-wave ground-intersection pattern, as represented by the heavy line, is essentially hyperbolic in shape. The pattern at the right is for an aircraft experiencing a lateral acceleration. The ray paths are no longer parallel;

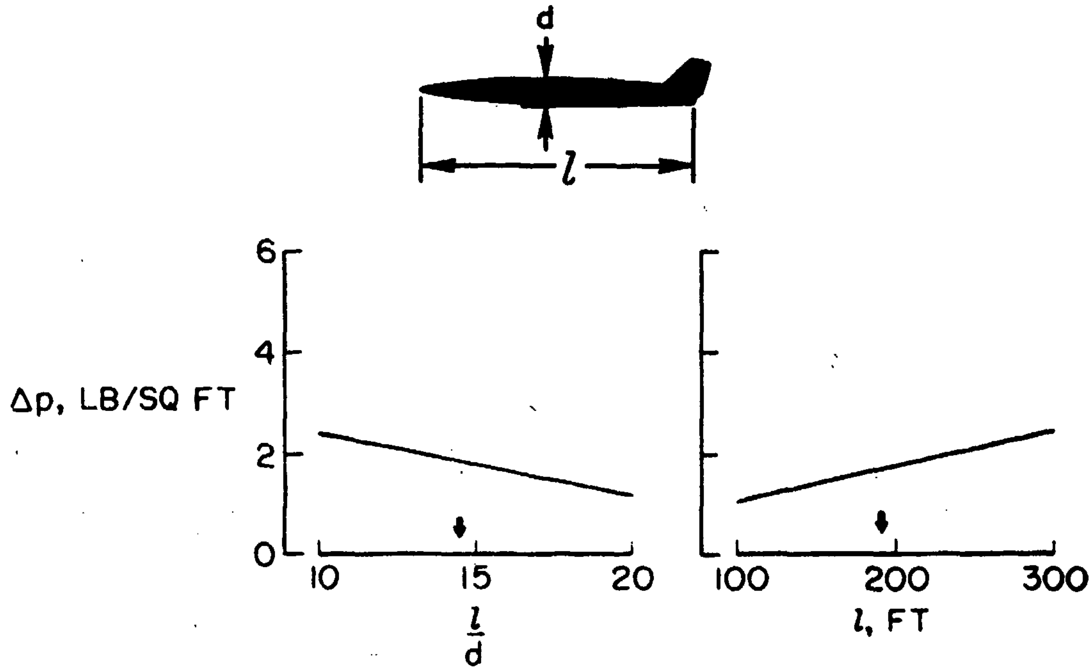

Figure 7.- Effect of aircraft shape and size on sonic boom.

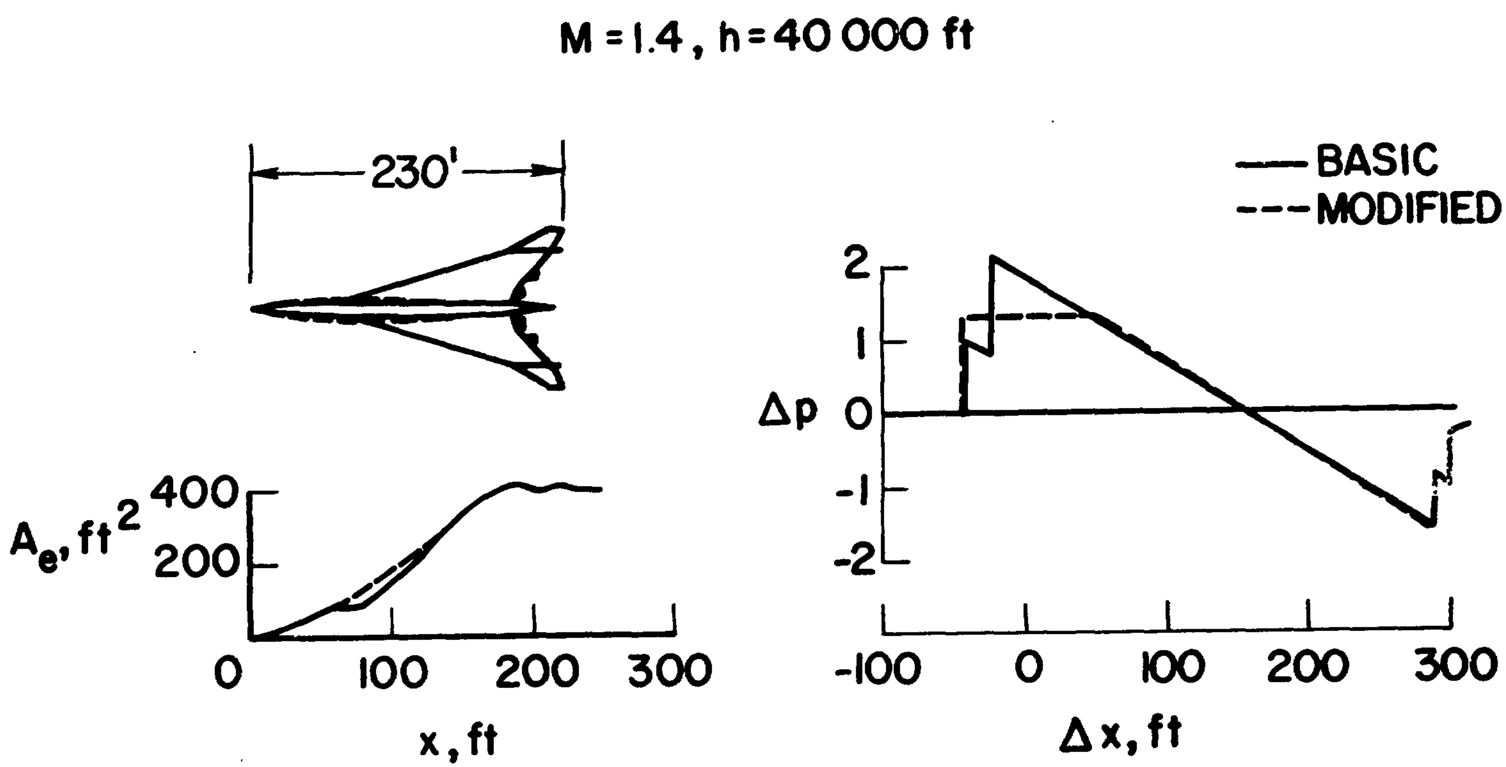

Figure 8.- Pressure signature for a basic and modified transport.

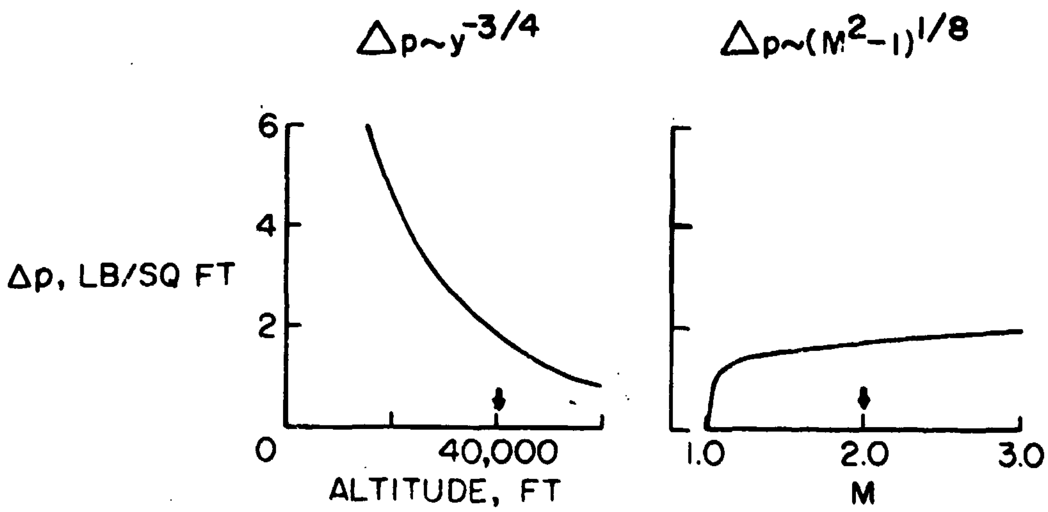

Figure 9.- Effect of altitude and Mach number on sonic boom.

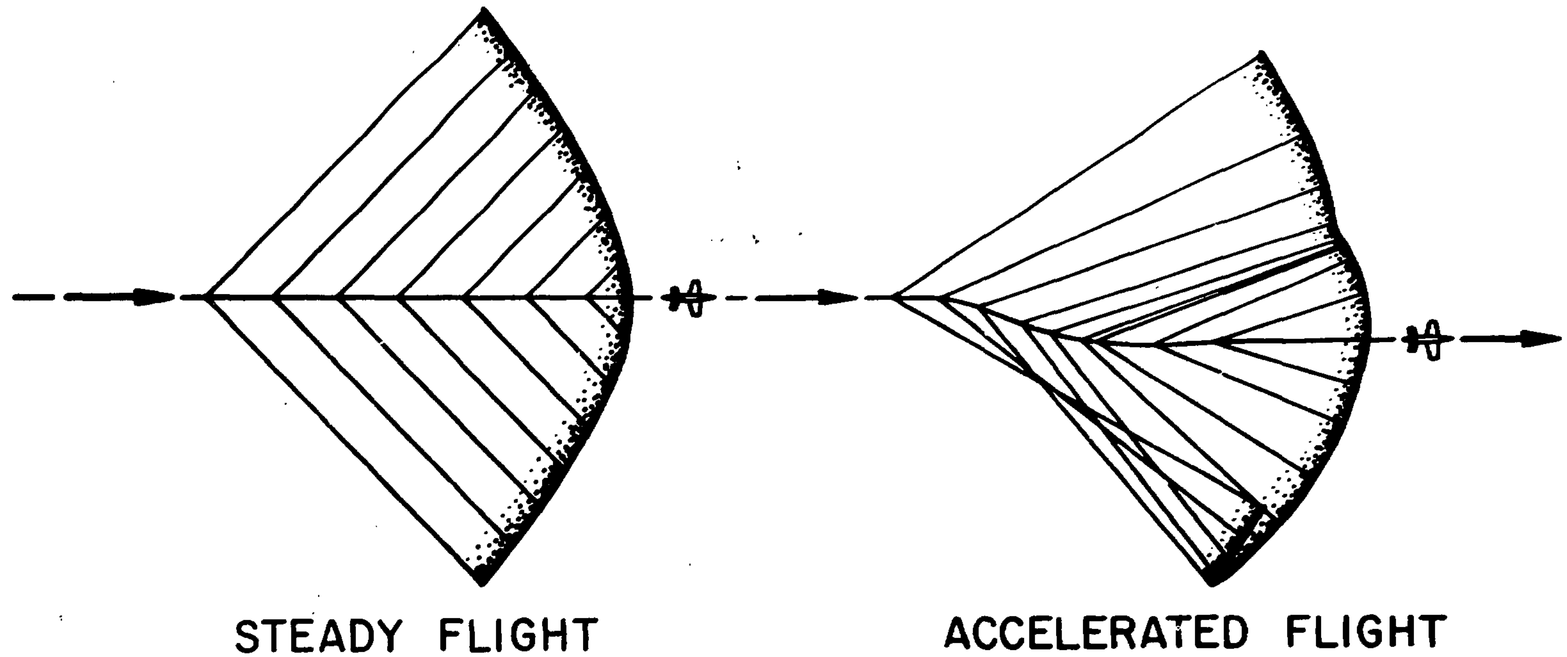

Figure 10.- Shock-wave ground-intersection patterns for aircraft in steady and accelerated flight at constant altitude.

in fact, in some regions they tend to converge and in others to diverge. Likewise, the shock-wave ground-intersection pattern is no longer hyperbolic and may contain some irregularities and cusp formations in which the pressures are higher than for the steady flight condition. Such pressure buildups are referred to as "superbooms," and while they may be several times as large as the corresponding steady-flight booms, they need not be large on an absolute basis.

III Environment

The propagation of sound through a uniform and constant medium is a relatively straightforward process. For the case of the sonic boom, the sound propagates through a real atmosphere having variations in pressure, wind velocity, temperature and turbulence, and these parameters can drastically alter the shape of the sonic boom signature. To illustrate this point, pressure histories are present in figure 11, where we measured the overpressure at five stations located only 200 ft. apart from the straight and level flight of a single airplane. We obtained differences in the signature which varied by a factor of three in the overpressure. Also, the shape of the signature changed drastically from a peaked signature to a well rounded and reduced overpressure signature. The measurements were made in a flat area with no building obstructions in the vicinity. We, thus, conclude that the changing pattern was due entirely to the atmospheric effect. We do not know the mechanism that causes this effect; for instance, is it a temperature effect, a diffraction associated with turbulence or vorticity, or wind shears? A considerable amount of research is being generated at the present time in an attempt to explain these anomalies. To obtain an idea of the variability in the measured overpressure, a number of flights by the B-70 airplane are shown in figure 12. Here, we have plotted on a probability chart the probability for equaling or exceeding a value of the ratio of the measured Δp to the calculated Δp. Results are provided for the winter season (the square points) and the summer season (circle points). The winter data fall on a straight line, which indicates the variation follows the normal or Gaussian distribution. On the other hand, it is not possible to fit a straight line to the summer data, indicating a non-Gaussian distribution. It is interesting to note that about 90 percent of the overpressure exceeded the calculated value for the summertime, whereas for the wintertime exactly half were equal to or above the calculated value.

PREDICTION TECHNIQUES

Methods for calculating the sonic boom signature are well in hand except for one area, namely, the effect of atmospheric distortion, although much work is going on in this area at the present time.

Most of the methods are based on some original work done by Whitham in England (reference 1), wherein he used slender body linear theory, but adjusted the shock and Mach wave location to correspond to the more exact nonlinear case. This approximation has worked out rather well, and the method has been computerized by Carlson and McLean at Langley Research Center (reference 2).

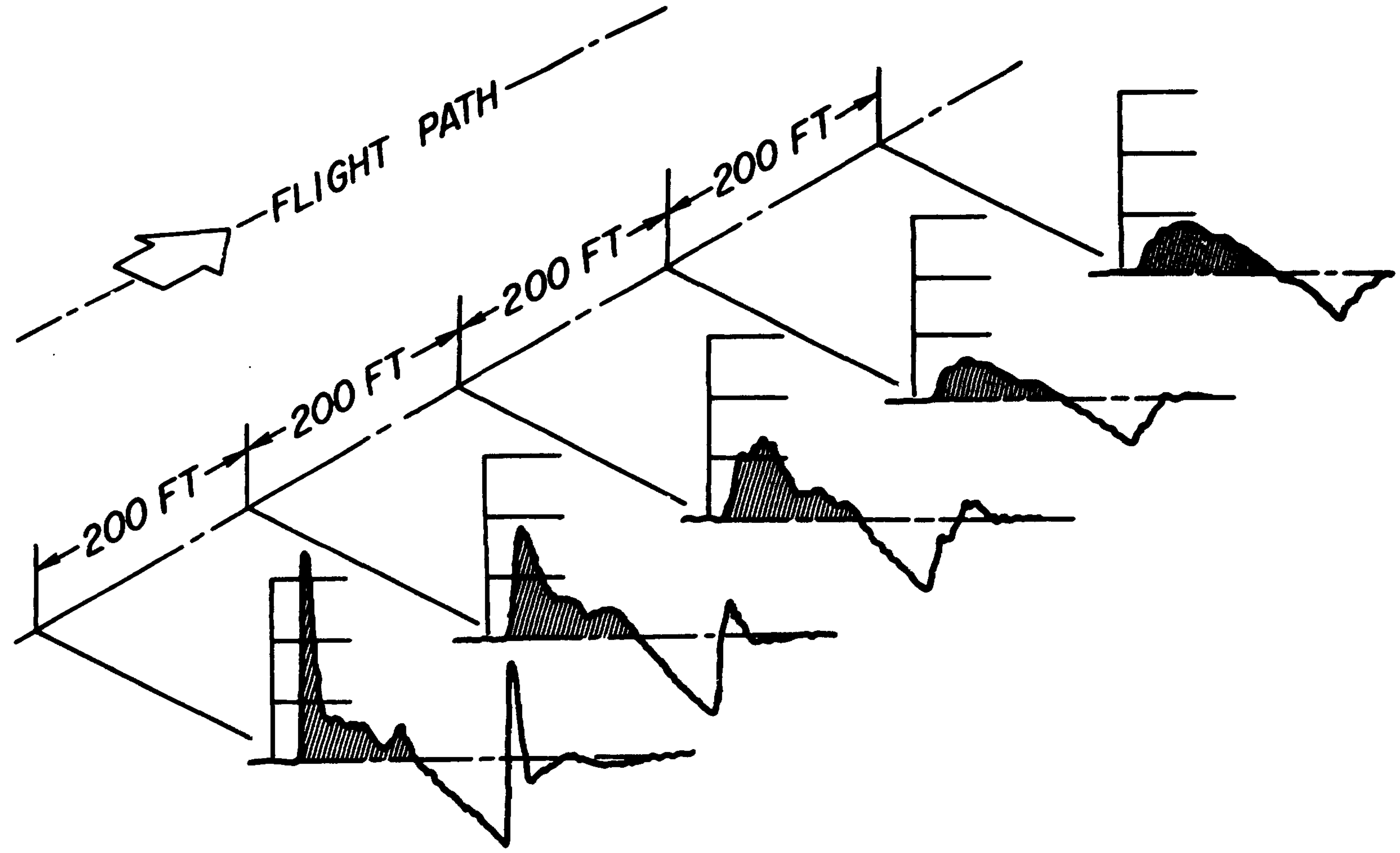

Figure 11.- Measured sonic-boom pressure signatures at several points on the ground track of a fighter aircraft in steady level flight at a Mach number of 1.5 and an altitude of 29 000 feet.

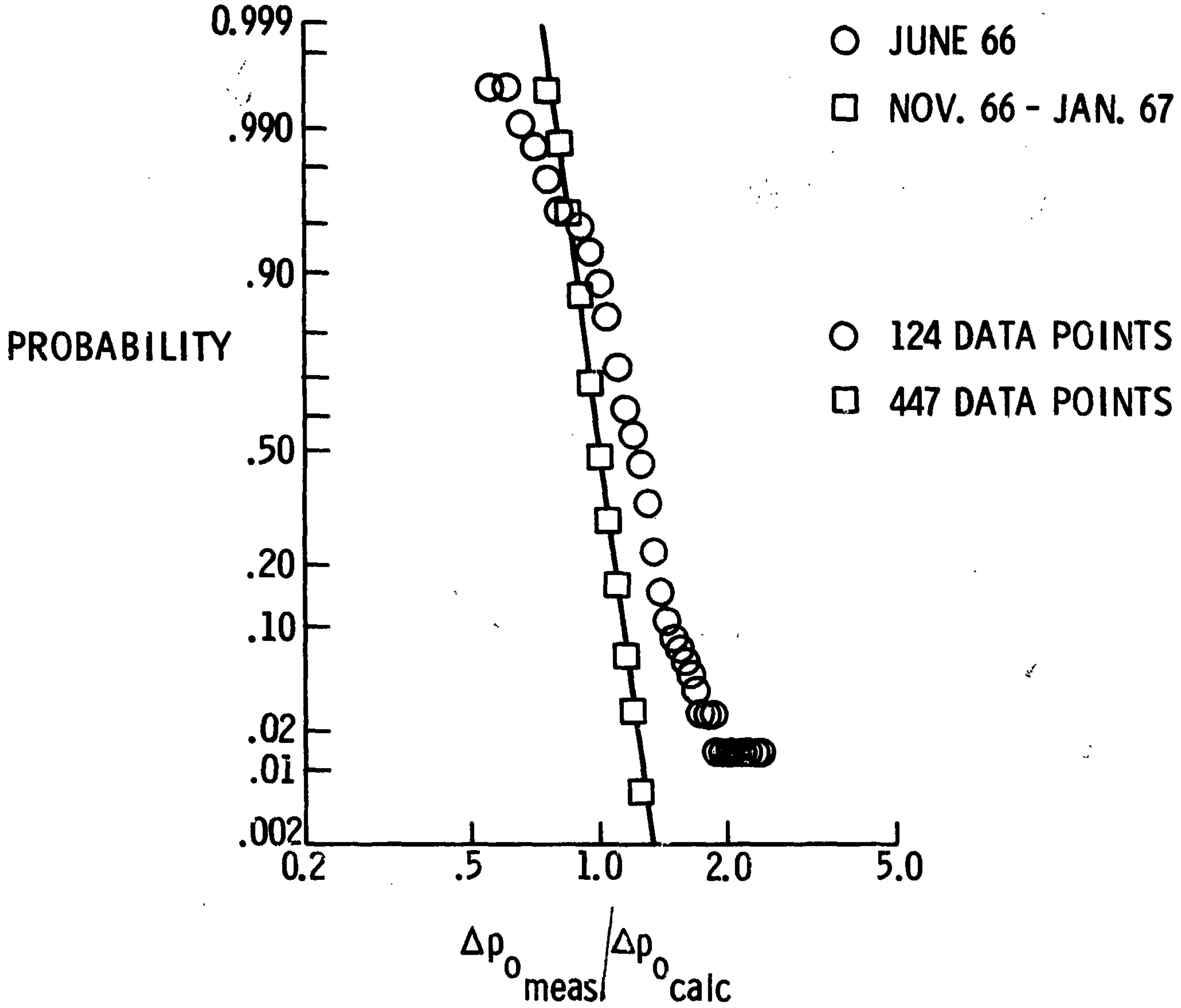

Figure 12.- Probability of equaling or exceeding given values of the ratios of measured to calculated ground overpressures for the XB-70 aircraft for the two different time periods.

However, DuMond et al (reference 3) were among the first to investigate the shock from a supersonic projectile and to study the resultant N-wave pattern.

PARAMETERS OF SIGNIFICANCE TO SONIC BOOM

The signature characteristics are of importance with regard to both the human factor problem as well as the building response. One of the principal elements in building response is the glass window, and some studies of window damage have already been made (reference 4). Figure 13 shows some characteristics which may be important. On the upper left is shown a signature, indicating the four most important parameters: overpressure Δp, duration of signature Δt, rise time τ, and initial impulse I (area). On the upper right is shown a possible signature with several shocks which might be spaced such that a structure could respond to the embedded frequency. Lastly, on the bottom is shown a Fourier spectrum of a typical N-wave, which illustrates the frequency content of the wave. All of these factors are important from the standpoint of human factors and building response, but will not be touched on in this paper. An excellent reference which contains most of the latest information (reference 5) resulted from a Sonic Boom Symposium sponsored by the Acoustical Society of America in November 1965.

CONCLUDING REMARKS

The purpose of this paper was to present the origin of the sonic boom, some of the characteristics of the boom, and then to describe some of the factors which influence the boom. The three main factors may be classified as aircraft configuration, aircraft operating condition, and observer environment.

Changes in aircraft configuration were shown to have a rather large influence on the boom signature; relatively small geometric changes can have large effects. Of the operating characteristics, it was shown that increasing the altitude has a very large effect in reducing the maximum boom overpressure, but acceleration and maneuvering can cause booms of high magnitude in local areas. The weather environment was also shown by actual measurements to cause large perturbations on the nominal boom signature.

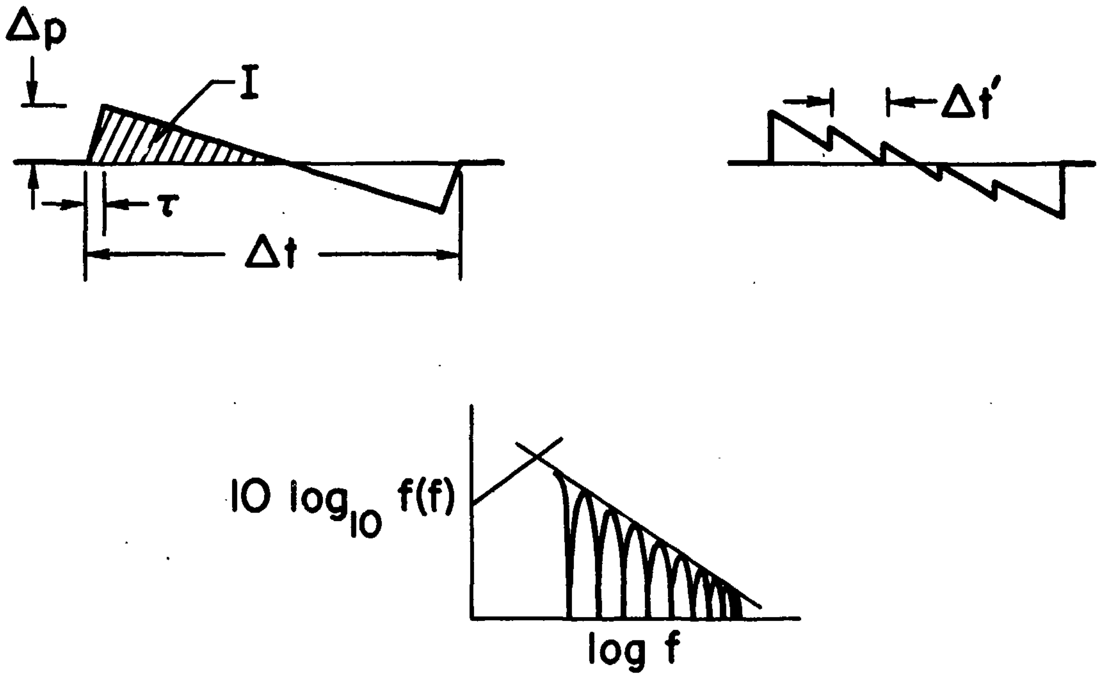

Figure 13.- Parameters important for response.

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STRUCTURAL RESPONSE TO SONIC BOOMS

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Dr. Kryter and Mr. Runyan have aptly described the startle effect and the signature characteristics of sonic booms. The pulse shape is roughly an N-wave with duration of the boom varying from about 0.08 seconds for Century series fighter aircraft, to 0.16-0.17 seconds for the B-58 and SR-71, to 0.25-0.30 seconds for the XB-70 and a predicted 0.35 to 0.4 seconds for the future supersonic transport (SST). The rise times vary from 0.0015 seconds to 0.007 seconds depending on whether the aircraft is overhead or is laterally offset from the observer. Overpressure for routine military aircraft flights may vary from two to six psf. For comparison, a 22-mile per hour wind should produce an overpressure of 2 psf on a flat vertical surface. One might wonder then if "the bark may not be worse than the bite," that is, the noise and startle effect may be much worse than the physical effects on structure elements. The data presented in this paper will illustrate the type of structure response and possible damage to be expected from sonic boom. The data were primarily collected during sonic boom experiments at the White Sands Missile Range and at Edwards AFB. Other sonic boom tests have been conducted at St. Louis and Oklahoma City.

Summary

Measurements of the response of test structures to sonic booms of different overpressure levels and different aircraft were made during two test programs. The tests were conducted at White Sands Missile Range, New Mexico, from 18 November to 15 December 1964 and from 15 January to 15 February 1965, and at Edwards AFB, California, during June 1966 and from 31 October 1966 to 17 January 1967. The White Sands program was conducted by the Federal Aviation Administration, with supersonic aircraft missions by the U. S. Air Force. The Edwards AFB experiment was conducted by the National Sonic Boom Evaluation Office, USAF. John A. Blume & Associates Research Division was intimately involved in both programs.

The results of the tests and analyses of the data obtained confirmed that structure response can be predicted if the characteristics of a structure element and the peak overpressures and pulse duration of the sonic boom are known. The tests also showed that it is highly improbable that damage will occur from sonic booms with overpressures of 2 to 3 psf in buildings that are well designed and constructed, and properly maintained. Investigations of the damage complaints resulting from the Edwards test flights indicated, however, that some damage may occur to other buildings not so constructed or maintained when subjected to overpressures of this

level. The results of tests showed that the response of structures to aircraft such as the XB-70, B-58, and F-104 can be extrapolated to the future SST.

Analysis of the investigation reports of damage complaints from the Edwards Program also indicated that about 80 per cent of valid damage claims were for damage to glass. A valid claim was one where the engineering investigator determined that the damage could have been caused by a sonic boom. The remaining valid claims were for bric-a-brac or other objects falling from shelves, cracking of plaster or gypsumboard walls and ceilings, or miscellaneous damage such as poorly hung pictures or mirrors falling.

White Sands Tests

The primary purpose of the White Sands Program was to study sonic boom damage index levels associated with different types of structure materials such as plaster, gypboard, glass and masonry. Seven new test structures were constructed as shown in Figure 1. Structures C-1, W-2, W-3, W-4 and 2S-5 were each 16 by 32 feet in plan with three rooms and basic finish materials as shown. PF-6 was finished with gypboard for Part A of the tests and plaster on gyplath for Part B. A section of a greenhouse was also constructed. The structures were instrumented to measure plate deflections of walls and glass panes, and racking deflections of the structures. In addition to the test structures, fourteen other existing buildings including five old ranch houses and range buildings were subjected to booms. A total of 1,494 booms were generated at the site, 1,433 from F-104 aircraft and 61 from B-58s. Boom overpressure levels were scheduled ranging from 1.6 to 19.0 psf. The maximum recorded was 24 psf and one unscheduled boom generated about 38 psf.

Racking displacements in the longitudinal direction at the roofline of the two-story structure (wood lath and plaster) of about 0.0035" at overpressures of 2 psf were observed. At 5 psf overpressure these displacements doubled and at 8 psf they tripled. Similar results were noted for the one-story structure with gypboard interior finish, 0.002" displacement at 2 psf, 0.004" at 5 psf and 0.008" at 8 psf overpressure.

The center of an 8' by 26' wall panel deflected about 0.018" at 2 psf overpressure, 0.03" at 4 psf and 0.062" at 8 psf. The same point on the wall deflected 0.07" under a 200-pound load statically applied at the center of the wall. No cracking was observed under the static load or the boom loading.

Relatively minor damage occurred during the tests. At one boom of about 8 psf a hairline crack extended slightly in the ceramic tile on a shower wall. A casement window broke (glass fell outward) in one structure under a boom of 21.5 psf, Figure 2. The glass cracked first near the window latch and then progressed in a radial pattern. No discernible damage occurred during booms of 2 to 3 psf maximum overpressure.

Free-Field Microphone Tower

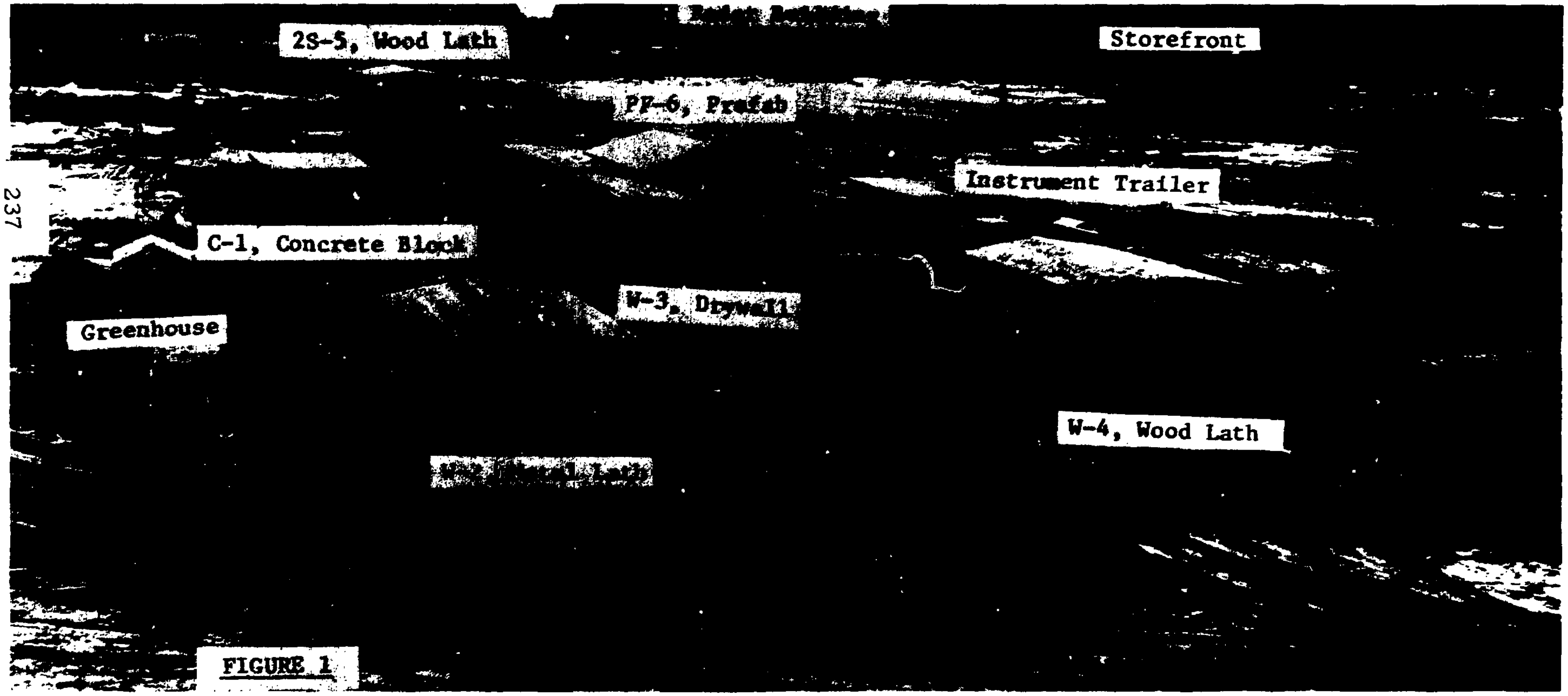


FIGURE 1

FIGURE 2

In summary the tests at White Sands indicated that structure damage should not occur at overpressures of 3 psf or less, to structures that are well constructed and well maintained.

Edwards Tests

The Edwards tests were conducted to compare subjective and structural response to boom overpressure levels from 0.75 to 3 psf produced by different sized aircraft. In this paper we are concerned with structure response. In addition to measuring and analyzing the test structures, all claimed boom damage to buildings at Edwards or in the adjacent communities was investigated and evaluated. Two test houses typical of contemporary midwest construction were built and instrumented. The houses were wood-frame with gypboard interior wall covering and redwood exterior siding. Figure 3. The houses were furnished completely with all normal appliances, furniture, dishes, rugs and drapes. A total of 357 sonic booms were produced during the two phases of the program, including 20 XB-70 missions, 163 B-58 missions, 74 F-104 missions plus numerous SR-71 missions.

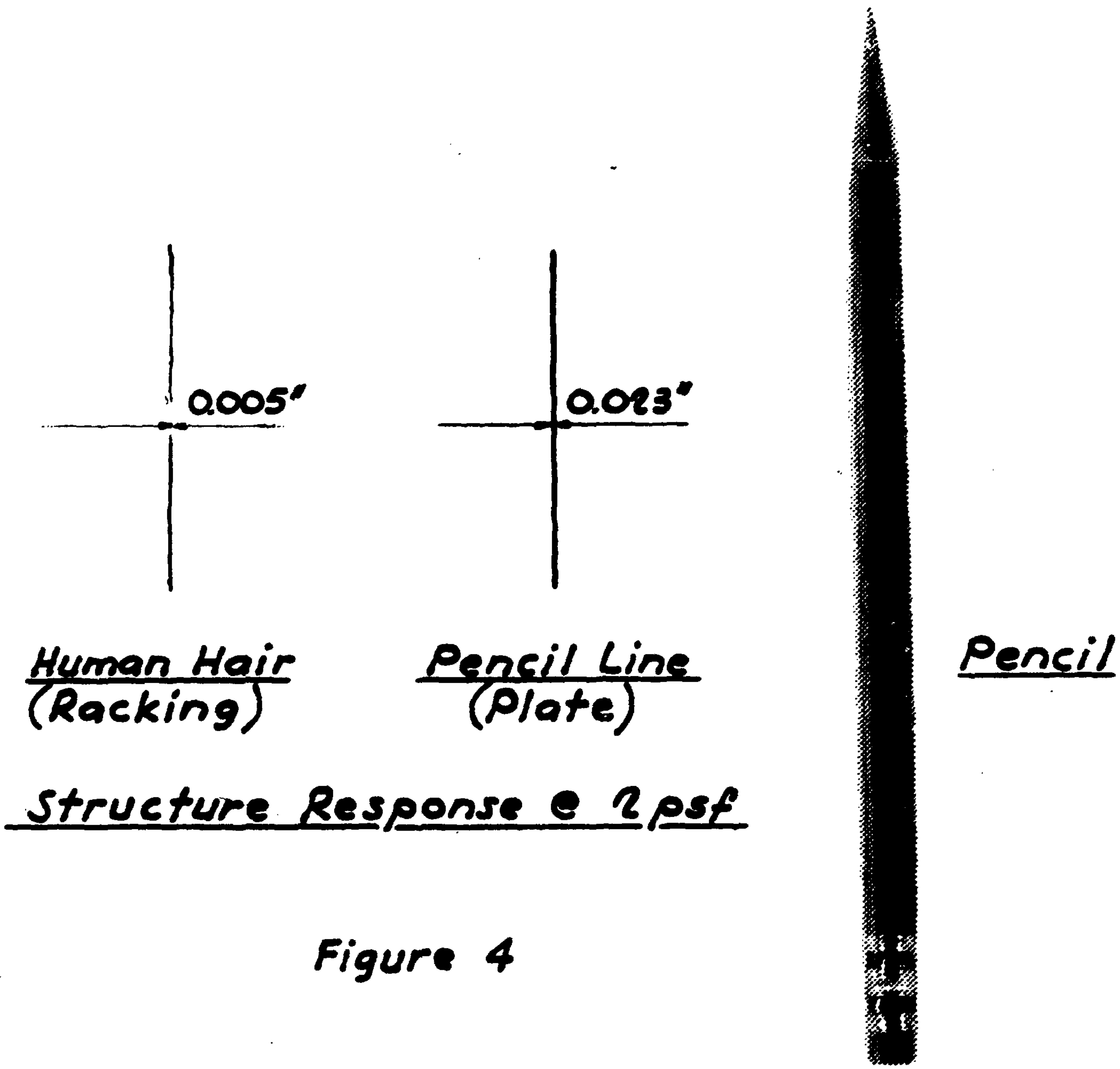
Maximum racking displacements at the roof line of the two-story house were recorded at 0.005", or roughly the thickness of a human hair. Maximum plate displacements in a wood study wall 8' x 13' were recorded at 0.023" (F-104) or roughly the thickness of a pencil line, Figure 4. The displacements in both the racking and plate mode compared quite well with White Sands. The dynamic amplification of the structure response when subjected to the test mission booms varied from 1.5 to 2.4. The structure frequencies at which maximum dynamic amplification occurred differed with boom pulse duration. Large aircraft produced booms of longer duration than smaller aircraft. Dynamic amplification factor (DAF) versus structure frequency is plotted in Figure 5. Note that the curve shifts to the left for the larger aircraft. Hence, the maximum DAF for the SST should occur for structure elements with a frequency range of 1 to 5 cps.

Structure response calculated by using free-field overpressures, dynamic amplification factors (DAF) computed from the free field signature and computed structure characteristics compared very well with measured response. Figure 6 shows a plot of computed (or predicted) response with measured response.

General

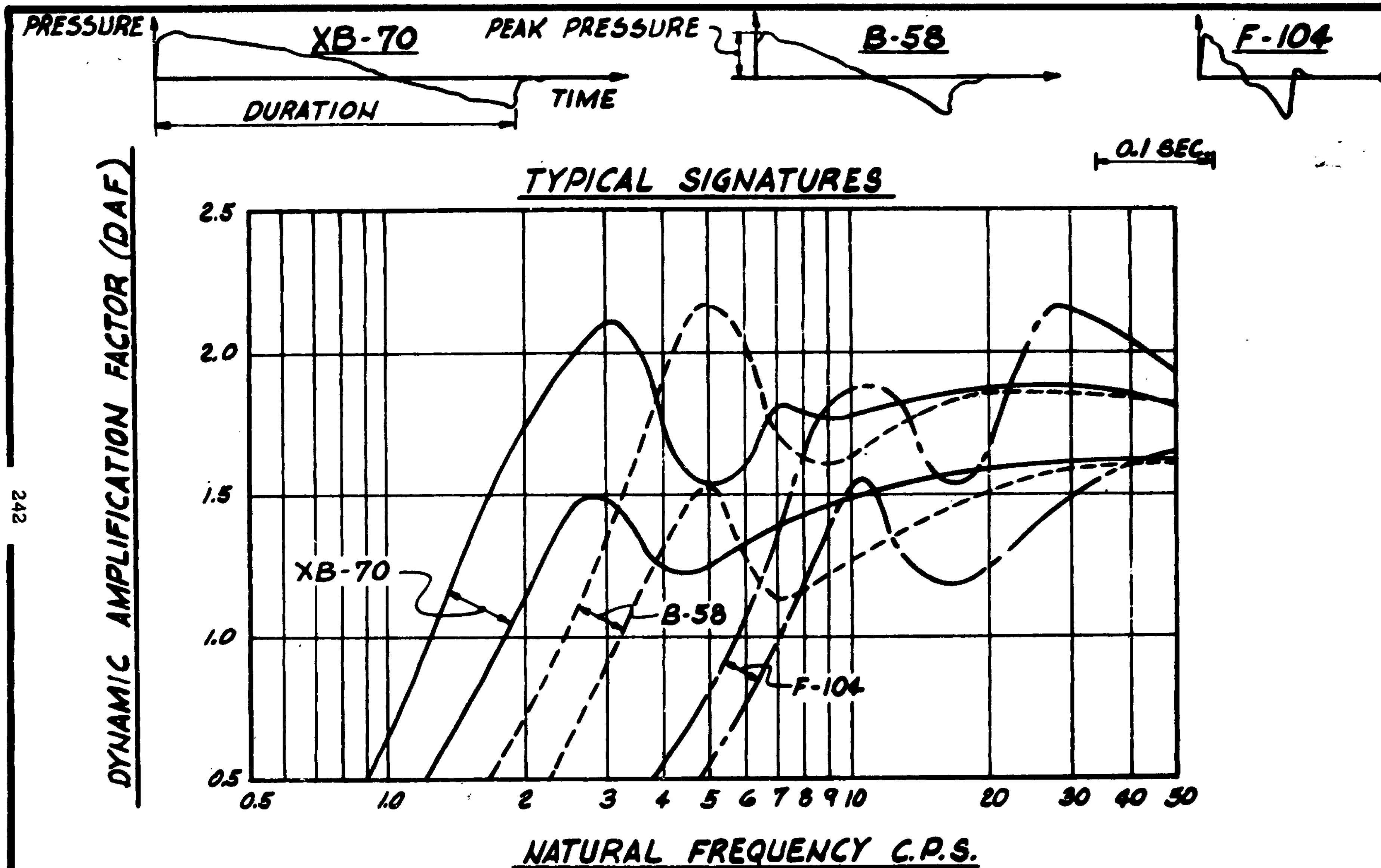
Sonic booms greatly in excess of the 2 to 3 psf level have been produced and have caused considerable damage--generally by accident. On 5 August 1959 an F-104 jet fighter made a low level pass and then climbed over the Ottawa, Canada airport.[3] The minimum altitude was about 500 feet. All of the glass in the nearly completed control tower was shattered and some structural damge including ripped roofing was suffered. In another incident an F-4 aircraft on a training flight made a low level pass and climbing turn over Washington Courthouse, Ohio on 9 June 1966. Many of the glass storefronts and other windows were shattered. Some structural damage such as cracked plaster was

Figure 3



Structure Response @ 2 psf

Figure 4



ENVELOPES OF RESPONSE OF 2% DAMPED SYSTEMS TO FREE FIELD LOADING

FIG. 5

FIG. 5

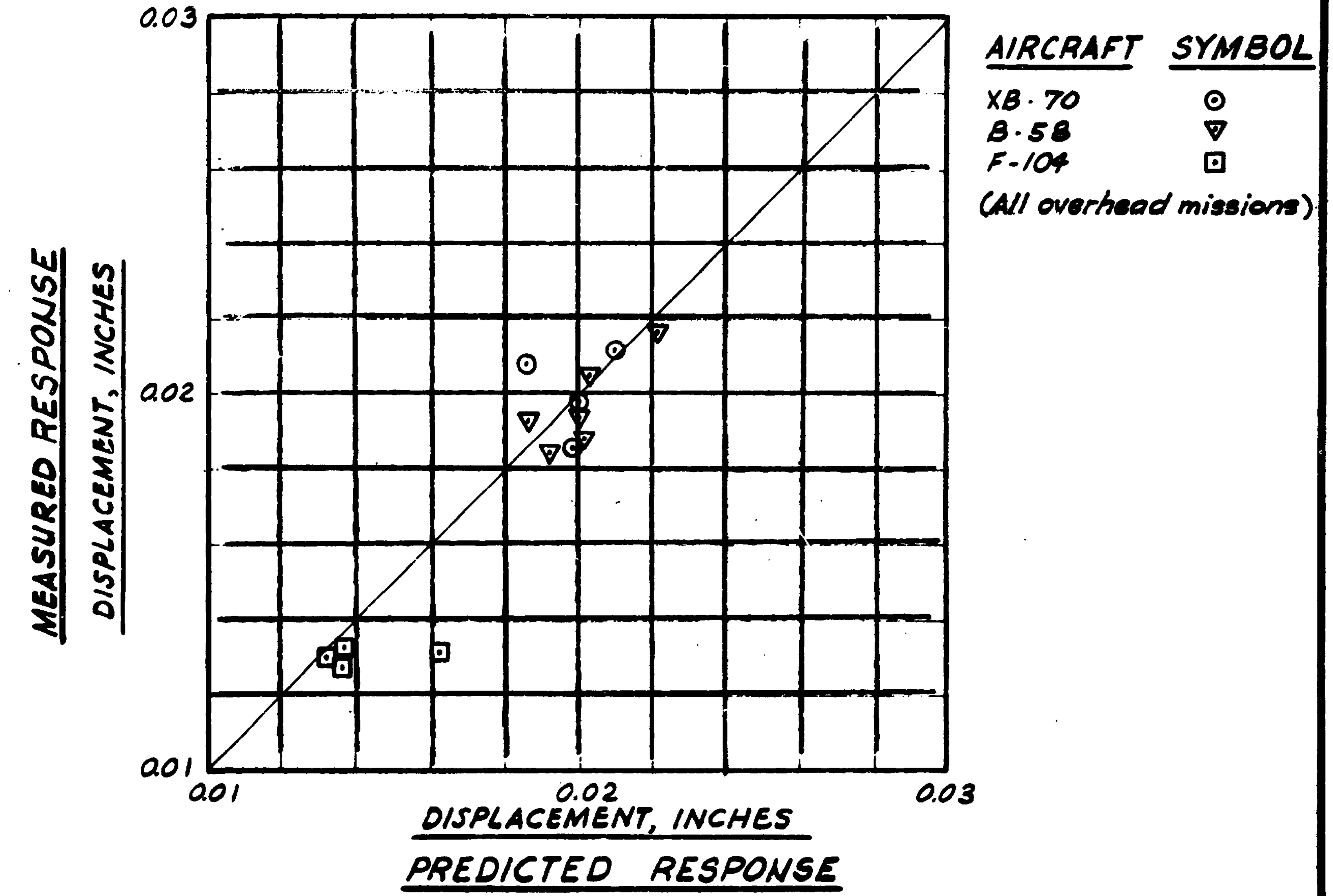


FIG. 6

MEASURED RESPONSE vs. PREDICTED RESPONSE
BASED ON FREE FIELD SIGNATURES EAST WALL BR1, HOUSE E-1

FIG. 6

reported. No pressure measurements were possible for either of these flights; however, estimates indicate that the overpressure was in the range of 20 to 50 psf. In both cases roughly half of the shattered glass fell into the buildings and half outside. If an aircraft flies supersonic at very low altitudes there is the possibility of considerable damage from sonic boom.

There is considerable evidence that structure damage may occur from sonic booms with peak overpressures of 2 to 3 psf. Many thousands of complaints have been filed since 1955. As all of the complaintants could not be wrong, some damage must obviously occur from low overpressure booms, under some conditions. Many factors can contribute to damage--particularly in glass. Conditions such as loose or missing putty; supporting clips at widely spaced points; existing cracks, scratches or chips; and existing stresses due to temperature differential, shrinkage or settlement in the structure can create situations where minor vibration or loading could cause failure. These are factors that are not clearly understood--both as to whether or not they occur and if so how often?

In conclusion it should be pointed out that the primary discussion herein dealt with sonic boom overpressure levels of low magnitude--2 to 3 psf. For these sonic boom overpressure levels, there should be very little damage.

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THE THREAT OF SONIC BOOMS TO EXPLOSIVES FACILITIES

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Abstract

Aircraft flying at supersonic speeds can generate air shocks with pressures that are in the range of 1 to perhaps 100 pounds per square foot, depending upon air speed and altitude (or slant range distance). Direct initiation of even very sensitive materials, such as initiating explosives and nitroglycerin, is not possible with the shock pressures associated with sonic booms. Windows may be broken by shock overpressures as low as a few pounds per square foot, and falling glass or glass translated by air shocks could initiate impact-sensitive explosives. Repetitive sonic booms may cause bottles to walk to the edge of shelves and fall. Startle reactions engendered in individuals handling explosives could cause them to drop the explosives; however, individuals quickly adapt to repetitive sonic booms and experience in explosives plants does not suggest that the startle reaction is a serious problem.

* * * * * *

Aircraft flying supersonically generate shocks with overpressures that depend upon the Mach number of the aircraft, the distance to the target and the atmospheric conditions. The duration and character of the wave pattern is similarly influenced by the type of aircraft and its distance from the observer. It is anticipated that shocks from supersonic transport aircraft could generate overpressures ranging from 2 to 4 psf, with a total signature time of about 0.3 sec, of which one-half would be a positive overpressure decaying from a maximum more or less linearly to zero. Experimentally, shock overpressures greater than 120 psf or about 1 psi have been generated by an F-4C flying 100 feet over the course.[1] In the same experimental series, windows were broken at overpressures of 10 to 20 psf; window damage may have occurred at even lower pressures.

The reaction of a structure to a sonic boom depends greatly on the impedance match of the air shock to the structure, which in turn in largely defined by the dimensions of the shock and by the dimensions and construction of the building. In all but the most ruggedly constructed buildings, significant vibration will occur and sound will be transmitted to the interior;

these will be sensed by personnel inside the building. Human beings are extremely sensitive to vibrations. According to Crandell,[2] a displacement as small as 0.0004 inch at a frequency of 10 cycles per second is easily noticed, and one-third the displacement set by Duvall and Fogelson[3] for minor damage to structures (plaster cracking, etc.) affects people severely, Thus, an unadapted individual may be startled by the sound and vibration from sonic booms. This seems borne out by the reaction of people in at least two explosives plants subject to relatively intense but unmeasured sonic booms. In these plants, personnel are reported to have run outside to learn the cause of the sound and vibration. If an individual were handling explosives or explosive devices, it is conceivable that he might drop them, perhaps causing an accident. On the other hand, experience in explosives plants, particularly plants where test shots are fired or where accidental shots occur in burning grounds, indicates that this is a very improbable occurrence. In particular, it seems probable that when repetitive sonic booms are experienced, especially on schedule, as would be the case with supersonic transport flights, individuals would soon become accustomed to them.

The sound effects and vibrations caused by a sonic boom are somewhat different from those of explosive shots, particularly large explosive shots at long distances which involve longer times and where the negative pressure phase is much weaker and prolonged. However, British researchers have found that sonic booms can be simulated readily by firing pairs of explosive charges[4] to produce the double clap characteristic of a sonic boom.

A second possible consequence of building vibrations is the disruption of automatic controls provided by sensitive instrumentation. A recent incident has been reported that involved a run-a-way reaction in a continuous nitrator. The reaction was under the control of a temperature recorder-controller which failed as the result of (probably quite intense) building vibrations caused by nearby explosions in a dynamite mixer. No estimate of the shock level is available for this incident and no threshold limit for failure of instrumentation can be given with confidence. Except for extremely sensitive equipment, a threshold of about 1 psi may be chosen. Of course, installations can be made to provide some isolation from vibrations in critical situations.

There has been very little experimental work that applied directly to the question of initiation of explosives by air shocks. Gey and Bennett[5] subjected a number of initiating explosives to shocks in argon. They found the most sensitive material to be lead styphnate; it could be initiated by shocks of Mach 4 to 4.5. Friedman[6] subjected a variety of explosives, including lead azide and nitroglycerin, to the high temperatures associated with reflected shocks of short duration. He reports limiting conditions that required at least 830° K (1034° F) for the initiation of lead azide,

which corresponds to a shock of more than Mach 3, and about 715° K (827° F) for nitroglycerin, corresponding to a shock of Mach 2.76. Erikson[7] reports that lead azide in colloidal form was initiated by shocks of Mach 2.6, corresponding to about 100 psi overpressure.

In recent Bureau of Mines' investigations, fine-grained low-density RDX and PETN have been initiated by gas detonation of stoichiometric ethylene-oxygen at an initial pressure of 1 atmosphere. The incident pressures were of the order of 2000 psi. The temperatures which were of the order of 2800-3000° K (4580-4940° F) are very much higher than would be associated with air shocks of these pressures. The induction times were tens of microseconds, suggesting an initial deflagration that ultimately converted to a detonation. The pressures at transition to detonation are typically in the range of about 2 kilobars at the time of transition. Similar pressures were required for initiation of these materials by a variety of techniques including explosive-derived shocks and projectile impact. In all cases the shocks required to initiate these explosives were orders of magnitude greater than those associated with the most intense sonic boom.

If one takes data from Henkin and McGill[8] and assumes extreme conditions, namely that the temperatures associated with reflected shocks are maintained for a duration of 0.2 sec, which is longer than the total positive pressure of the N-shaped signature of a sonic boom, one can estimate conditions required for air-shock initiation. Under these conditions lead azide requires a temperature of 938° K (1230° F). Assuming that the initial temperature of the azide is 120° F, a shock pressure of about 42 atmospheres would be needed to initiate it. Tetracene, which appears to be about the most sensitive to thermal initiation of the common initiating materials, would have an estimated temperature of 200° C (392° F) for explosion in 0.2 sec; this corresponds to an overpressure of more than 4 atmospheres, or about 65 psi.

It seems very clear that there is no possibility that the most sensitive explosives will be initiated by shock heating from sonic booms. The temperatures for such initiation would require air shocks with amplitudes about 100 times greater than those of the most intense sonic booms from supersonic aircraft at low altitude and between 1,000 and 10,000 times greater than those associated with sonic booms of aircraft in normal high-altitude flight.

Repetitive booms could cause accidents by the effect that building vibrations have on bottles and other containers. In sonic boom trials and in areas where large explosive shots were fired repetitively, it has been observed that bric-a-brac tends to walk across surfaces. Containers that are used routinely are generally returned to their proper position, but sample or reagent bottles that are relatively unused could walk to the edge of the bench or shelf and fall. Sonic booms in the range of a few pounds per square foot have been known to have this effect. Although this again seems to be a rather far-out possibility of hazard, it probably should not be completely ignored in a laboratory dealing with explosives.

The possibility of nitroglycerin being initiated by falling glass and metal fragments was investigated in a brief, crude experiment. A total of 300 grams of glass shards having an average major dimension of about 1 inch was dropped 10 feet onto a 1/16-inch film of nitroglycerin on a 1/2-inch-thick steel plate. No initiation occurred, although we know that such a film of nitroglycerin on steel plates is readily initiated by weak explosive-derived shocks. Similarly, there was no reaction when about 300 grams of 1/2-inch diameter steel balls were dropped 10 feet on the same type of nitroglycerin sample. In a third experiment, a 12x12-inch double strength window glass pane was broken by means of a falling steel weight. The shards and weight fell 10 feet onto a similar nitroglycerin sample without initiation. Glass or steel balls falling 10 feet would have a velocity of 25 feet per second on impact assuming no air drag. For comparison, window glass would have this translational velocity after being subjected to a blast from a 1-kiloton bomb at about 1-1/2 miles distance. No firm conclusions should be drawn from these limited results. The impact pressures are great enough to cause initiation if the environmental circumstances are just right. In particular, solid initiating compositions should be easily initiated. However only an intense sonic boom, much more intense than to be expected from routine flights, would cause comparable glass breakage and particularly significant lateral translation of the glass.

In conclusion, explosives plants should be equipped with blast-resistant glass in windows. Although sonic booms should break only poorly supported or prestressed window glass, very sensitive initiating explosives, especially those that are used for stab initiators, could be initiated by falling glass.

The potential hazards from sonic booms are summarized in Table 1 together with the estimated magnitudes of the shock strength required. Only the startle reaction and bric-a-brac movement fall in the range of ordinary to heavy sonic booms (1-3 psf). Window breakage will occur with heavy to very intense booms.

TABLE 1. - Sonic Boom Hazards

	Psi	Psf
Direct Initiation of Explosives	$10^2 - 10^4$	$10^4 - 10^6$
Instrument Reaction	10^0	100
Window Breakage	10^{-1}	10 - 20
Bric-a-brac Movement	10^{-2}	3 - 5
Startle Reaction	10^{-2}	1 - 2

Given a properly designed and constructed explosives plant, it seems quite unlikely that even very sensitive explosives would be initiated. The possibility that personnel could be startled by sonic booms into causing accidents cannot be overlooked. However, experience in explosives plants suggests that this is not a very probable hazard. There seems to be no clear history of chain-reaction accidents occurring due to startle of explosives plant personnel.

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BALLISTIC INVESTIGATIONS OF FRANGIBLE PROTECTIVE STRUCTURES FOR SPACE VEHICLES - POTENTIAL APPLICATIONS OF FRANGIBLE CONSTRUCTION

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ABSTRACT

The ballistic effectiveness of frangible structures for protection about space vehicles on launching pads was studied analytically. Requirements for evaluating effectiveness are discussed. Supporting experimental tests were conducted to obtain some of the inputs required, particularly those relating to the effects of fragmentation and blast on frangible structures. The ability of lightweight aluminum honeycomb panels to stop fragments and withstand the shock generated from space vehicle explosions is indicated. Ballistic limiting factors and information gaps are discussed.

POTENTIAL IMPACT OF FRANGIBLE STRUCTURE CONCEPTS ON FUTURE ACTIVITIES IN SPACE

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During the past several years, considerable interest has developed regarding the concept of what I have called "Frangible Structures." In a general way, my definition of a frangible structure is one that provides the environmental control necessary for its function, but which in event of an explosion within or adjacent to it, will offer minimum confinement of blast, and will fail in such a manner as to form fragments having poor flight characteristics after breakup. Theoretically, such structures can be designed to attenuate the primary fragments of greatest potential range. This is where I believe we may realize the greatest benefit from such structures.

My discussion today will serve merely as an introduction, as a result of my past involvement in the work being done currently at BRL, under the technical guidance of KSC, and in impressions which are purely my own, as to how such work may be related to and may affect future space activities.

My association with this concept (frangible structures) began as a result of ideas and suggestions of Mr. E. Straight of KSC and Mr. H. G. Buchanan, BRL concerning the use of honeycomb plastic, or laminar plastic structures for storage of explosives and ammunition. The properties of this type of material seemed promising. When planning static test facilities at MILA, it became apparent that conventional hardened construction was not feasible for use with the types, quantities, and explosives potential of the fuels involved. At this point the concept of attempting to confine an explosion in a "hardened" structure was dropped, and an attempt made to build structures with the maximum venting capability,

consistent with operating requirements, and constructed in such a manner that in the event of failure, secondary fragments, in terms of size, mass, and range, would be minimized.

At this same time, plans were made to conduct a test program to explore the characteristics of honeycomb materials as "frangible structures." These tests are currently being conducted by the BRL, and Mr. Dunn will report on these.

My efforts here will be to hypothesize regarding the application of these concepts to our future activities, as stated. Naturally, all of my hypotheses must be preceded by a big "if" -- namely, if the tests bear out the theory, a number of interesting things may be possible.

Looking ahead in space, we can see, hopefully, an order of magnitude increase in space activities, provided that methods can be found to reduce costs and improve reliability and safety to the point where such an increase is economically feasible.

One of the major costs incurred in building test or launch facilities is in providing for the necessary safety or separation distances between activities within a facility, or from the facility to locations outside the installation boundary lines.

Unfortunately, once the installation is sited and the necessary safety distances established, any appreciable increase in the number or bulk of testing activities beyond that originally planned for is usually quite costly. In addition, the overall squeeze brought about by the ever-increasing spiral of goods and services costs, makes it mandatory that we exact the most out of every facility dollar.

At the same time, as we have learned more about the blast hazard potential of our propellants, and have gotten an insight as

to how these hazards may be controlled, the fragmentation hazard becomes more and more the controlling factor.

For these reasons, it appears that any actions we may take to reduce costs of construction or siting while providing an equal or better standard of safety will be doubly important. This is where "frangible structures" enter the picture.

Quite simply, a theory has been advanced that it is feasible to design a structure which in the event of explosion of the engine, spacecraft component, etc., will remain intact long enough to provide some attenuation to the most far-ranging fragments, but which will not contribute secondary fragments beyond the range of the attenuated primary fragments, and will not provide sufficient confinement to increase the blast potential of the explosion.

If such proves to be the case, a number of courses of action become feasible. For example, if we desire to test an uprated device at an existing site, it may be possible to identify the "primary" fragments from a possible explosion, having the greatest range, and design a test structure such that these fragments will be attenuated sufficiently to fall within the ranges established for the original facility, without the creation of secondary fragment hazard from the structure. Similarly, additional tests of smaller size may be accommodated, at existing locations, with reduced operational interference. Additionally, considerable cost savings will be realized in the departure from massive concrete and armor plate structures, as well as in the reduced cost of facilities, GSE, etc. brought about by the reduction in separation distances. Furthermore, application of these principles to existing facilities may provide for further savings and increased safety.

For example, large sheet metal sections which presently might "sail" to great distances might be constructed of "scored" panels

designed for minimum fragment range. Since the materials selected for study thus far have good thermal properties, they might as originally speculated, prove superior to other materials for above-ground magazines, etc. A number of other potential uses come to mind, but I had better not get too far ahead of the test program. To me, the most significant factor which indicates that this concept bears studying is the fact that our modest investigations have indicated that generally speaking, the fragments from space vehicle explosions which have the greatest range are not good ballistic fragments, and for that reason are easier to attenuate.

BALLISTIC INVESTIGATION

D. J. Dunn and S. D. Schlueter, BRL

APPROACH

Before we examine the details of frangible panels as protective structures, it is worth considering the scope of our investigation and the approach we have taken. The scope is limited to the ballistic aspects of frangible panels, such as fragmentation and shock effects on panels including drag and distance. We do not attempt to cover construction aspects, weatherability, cost and other important considerations which would be involved in the application of frangible panels as protective structures. In our approach we have been guided by system concepts commonly employed in weapons evaluations. The system approach requires a delineation of the inputs required to permit a quantitative evaluation of the output desired. The important inputs are as follows:

1. Characteristics of the Damaging Agents.
2. Arrival Sequence at the Panel.
3. Effects of Frangible Panels.
4. Damage Criterion.
5. Measure of Effectiveness.

Our contribution to date to the above inputs is to item 3, the effects of frangible panels. Later in this report, we will illustrate a simple evaluation process by making use of published results from two S-IV vehicle explosions for item 1 and by assuming damage criteria and measures of effectiveness for items 4 and 5. We do not include the final step in a systems analysis which consists of comparing various alternative structures.

EFFECTS STUDIES

In the event of an accident 1 explosion of a space vehicle which is protected by a frangible structure, the damaging agents

can be classified into two groups as shown on Figure 1. The primary group consists of those agents striking the frangible structure (such as skin fragments, chunky fragments, the air shock and propellant gases.) The secondary group consists of those propagated beyond the protective structure such as the primary fragments which get through, and panel fragments.

We should note the impor ce of the sequence of events on the panel. In the event that a very strong shock arrives before any fragments, then the panel could be destroyed and have no effect on the fragments.

The effects which we have studied are listed below:

1. Fragment Velocity Attenuation by Panel.
2. Shock Effects on Panels.
   - Delamination
   - Blow Through
   - Fragmentation
   - Launch Velocity
3. Fragment Range.
   - C_D Determination
   - Construction of Range Tables

Our detailed ballistic studies of frangible panels have been confined to the aluminum honeycomb structural material. Three panel weights were studied. The lightest had .062" faces and weighed 3 lbs/ft^2; the heaviest with .188" faces had an area density of 7 lbs./ft^2. For comparative purposes a concrete panel weighing 7 lbs/ft^2 would be 0.6" thick. All panels were 1-1/2" thick and were supposed to be strong enough to withstand 125 MPH winds in 8 ft. x 10 ft. sizes.

VELOCITY ATTENUATION

The attenuation of compact-shaped fragments by a frangible panel was determined experimentally. Steel and aluminum cylinders were shot from guns into each of the three weight panels. The

limit velocity, V_{50}, at which 50% of the projectiles are stopped was determined for each projectile - panel weight combination. In addition, the attenuation in the velocity of perforating cylinders was measured, Reference 1. An analytical equation was fitted to the data as shown on Figure 2. By means of these equations one can compute the limit velocity, or, the residual velocity of a compact fragment which passes through a frangible panel.

SHOCK LOADING EFFECTS

Shock loading effects on aluminum honeycomb panels were also studied experimentally. The test facility is shown on Figure 3. Small panels, 2' x 2' in face area, were placed at various distances from a pentolite charge and were projected by the shock at a launch angle of 25°. Observations consisted of delamination of the panels, the maximum velocity of launch and the range attained. Charge to panel distances ranged from 3 ft. to 20 ft. and charge weights from 8 to 300 lbs. Pressure-time histories available in the literature for these charges, reference 2, were occasionally checked.

The onset of fragmentation of the shock loaded panels occurred by delamination of the face opposite the charge. Delamination is determined by shock pressure and impulse loading of the panel. Experimentally determined criteria are shown conceptually on Figure 4. By means of these criteria one can determine if delamination would be expected by a given honeycomb panel at a given distance from an explosion.

A more important effect of a shock on a lightweight panel is flexural deformation. When the shock intensity is large, the panel bends plastically to such an extent that it can pull out of its supports without fragmenting and be literally blown away. We have obtained a few test observations of blow through to date. Our work of this type is being assisted by experts in the structural response field.

The next degree of fragmentation of a panel is breakup of the incident face. Our test work on this type of breakup has only begun. We will be using panels having notched faces intended to breakup into predetermined sizes and so limit the mass of panel fragments which are projected by shock loading.

FRAGMENT RANGES

Our studies of shock loading of panels were coupled with studies of the drag coefficient of panels in flight and with the ranges they attain. Having observed the launch velocity and the resultant range, one can determine the average value of the drag coefficient. We found a rather high value of $C_D = 1.25$ applied to these panels based on the flat face area. We also checked predictions of the launch velocity based on the known reflected pressure and impulse, Reference 2, and distribution of loading, Reference 3, against observed launch velocities. Occasionally, a panel would fly to a much greater range than expected. This anamoly is believed to be due to lift and wind effects and to a lesser extent to the presence of an end-on orientation.

In computing panel ranges, we found it necessary to utilize a computer because data from the literature were so spotty and incomplete. To fill these gaps we constructed fairly comprehensive tables, Reference 4, for use in determining fragment terminal and summit values in the subsonic region. The scope of these tables is shown below.

ENTRIES:

1. Launch Velocities: 50, 100, 150, 200, 250, 300, 400, 500, 600, 800, 1000, 1120 ft/sec.
2. Launch Angles: 10 to 50 in 5° steps; 60, 75, 90°.
3. Values of $C_D \rho A/2M$: .0002 to .0450 ft^{-1} in 21 steps.

OUTPUTS:

1. Terminal Range, Time of Flight, Velocity and Angle of Fall.
2. Summit Range, Height, Time.

A result associated with construction of the range tables was the solution to the problem of the angle of launch which gives the maximum fragment range. The solution is shown on Figures 5 and 6.

ESTIMATED EFFECTS ON OBSERVED DAMAGING AGENTS

We now wish to provide an indication of the value of utilizing aluminum honeycomb panels as protective structures. To begin an analysis we need information on the characteristics of the damaging agents. We have selected from the literature data from two S-IV vehicle accidents. Table 1 shows fragment data from the S-IV vehicle accident at Sacramento in January 1964, Reference 5.

TABLE 1. S-IV ACCIDENT AT SACRAMENTO FRAGMENT DISTANCES AND WEIGHTS

Simplified Shape of Fragment	No.	Distance, ft. Max.	Distance, ft. Ave.	Weight, lbs. Max.	Weight, lbs. Ave.	Inferred Initial Velocity Ft/Sec
CYLINDER (ducts, tubes)	8	400	243	150	33	Low to Medium Subsonic
SHEET (skin, BH, skirt, dome)	25	1100	388	110	27	Medium to High Supersonic
OTHER	11	350		90		

NOTE: At least one fragment reached 1500 ft. but its details are unknown. Equivalent weight of TNT for blast = 1100 lbs. (1%).

We see that the sheet type fragments attained the longest distances, out to 1100 feet, whereas the more compact fragments reached only 400 feet. Now suppose that the S-IV vehicle was surrounded by an aluminum honeycomb panel. The fragment velccities indicate that the arrival sequence at the panel would be first the

sheet fragments, then the shock and finally the compacts.

Before discussing the anticipated effect of a lightweight structure on these fragments, it is necessary to point out an information gap. The long ranges attained by some sheet fragments cannot be explained with assurance. We need to know the orientation, shape, drag and lift coefficients of supersonic sheet fragments. At BRL we have observed subsonic sheet fragments in flight from an exploded Atlas missile. They bend and wrinkle appreciably in flight. At supersonic speeds we would expect drastic changes from a flat shape to a much more compact shape. Such a change in shape could explain the long ranges observed for sheet fragments. Another possible cause of the long ranges is the effect of lift. Lift can result in ranges appreciably greater than expected in the absence of lift. A third possibility is the existence of an end-on orientation in flight. Just which of these three possibilities or their combinations actually exist is important in determining the effect of a protective barrier on sheet-type fragments. If the answer is shape changes and/or lift, we calculate that a lightweight structure in the 5-15 lb./ft.^{2} range would have stopped the sheet fragments at Sacramento. However, if sheet fragments fly in an end-on orientation, a considerably heavier barrier would be required to stop them.

If we assume the optimistic alternative that the sheet type fragments can be stopped, we can go on to consider the shock and compact fragments. If the panel is blown-through by the shock, we obtain no protection from the compacts. However, if we assume that the panel withstands the shock, we can consider the effect of the structure on the compact fragments. From our penetration test results at BRL we calculate that a 7 lb./ft.^{2} lightweight panel

would stop the vast majority of compacts. A few would get through. The perforators consist of those compacts which happened to strike with an end-on orientation.

We will discuss panel integrity when struck by a shock in the next example, the S-IV planned explosion at Edwards Air Force Base. At Edwards the equivalent TNT yield was 3%, as compared to 1% at Sacramento, and the shock effects were more severe.

Table 2 summarizes the data on the long range fragments at Edwards Air Force Base.

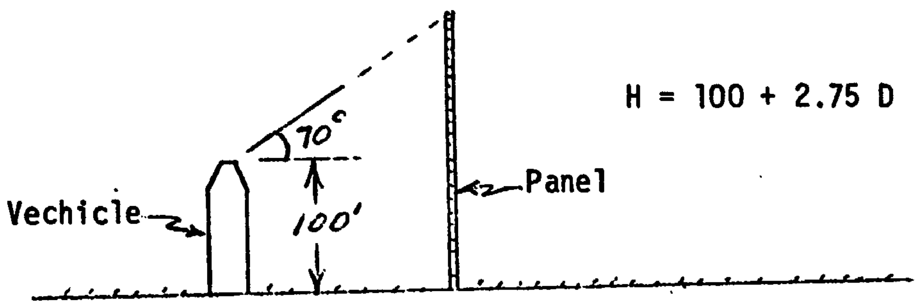
TABLE 2. S-IV VEHICLE EXPLOSION AT EAFB
FRAGMENTS TRAVELING BEYOND 600 FT.

Simplified Fragment Shape	Number of Fragments	Maximum Range, ft.	Maximum Weight, lbs.
Sheet	56	1030	19
Medium	13	1030	9
Compact	13	950	16

The range of the compacts is now comparable to the range of the sheet fragments. From these ranges we calculate that the arrival sequence at a hypothetical panel consists of the sheet fragments, followed by the shock and finally the compacts as before. Stoppage of sheet and compact fragments could again be accomplished by a lightweight panel in the 5-15 lb./ft.^{2} range provided the strike is not end-on. Let us now consider shock effects. The ability of a panel to withstand blow-through by a shock is a structural response problem and depends on the configuration of the panel, its strength to withstand the various modes of failure, the equivalent weight of charge and the distance between vehicle and panel. We have considered the flexural mode as the pertinent mode of failure. The implications of panel blow-through are shown on Table 3. Trade-offs to reduce the minimum blow-through distance are the panel weight per unit area and the width of panel between supports. The panel height for open roof construction was calculated for a 100 ft. vehicle height

TABLE 3. ESTIMATED PANEL BLOW-THROUGH DISTANCES
OPEN ROOF CONSTRUCTION 100,000 LB. PROPELLANT - YIELD 3%

Panel Weight Per Unit Area Lb/Ft^2	Width x Length of Panel, Ft x Ft	Minimum Panel Blow-Through Distance*, D, Ft	Panel Height, H, Ft
7	4 x 10	70	290
7	10 x 20	95	360
14	4 x 10	55	250
14	10 x 20	75	305



*Estimate based on limited tests and advice of O.T. Johnson, BRL, and J. Greenspun of J.G. Associates, Baltimore, Md.

and for stoppage of fragments projected at angles up to 70°. For open-roof construction, panel heights are large, Table 3, and fragments projected through the open top are unimpeded. As a result, a closed roof construction is desirable from the ballistic viewpoint. In either case, we can anticipate that blow-through will be an important determining factor in choosing a panel weight and size, in addition to fragment stopping capability, particularly for large weights of propellant. This statement is expected to hold for any protective structure as well as for aluminum honeycomb structures.

CONCLUSIONS

The following conclusions are limited to liquid-fueled vehicles:

1. Lightweight structures can stop the vast majority of compact fragments provided structural integrity to the shock is maintained.

2. Lightweight structures appear to be effective barriers to sheet type fragments but further work is needed to confirm this capability. In particular, the flight characteristics of supersonic sheet type fragments need definition.

3. When stoppage of almost all fragments is required, shock containment by use of a closed roof will be necessary.

4. The panel weight required for shock containment and fragment stoppage appears to be reasonable up to the S-IV vehicle size.

5. Tables are now available for estimating the range of fragments in the subsonic range. A graph provides the angle of launch resulting in maximum fragment range.

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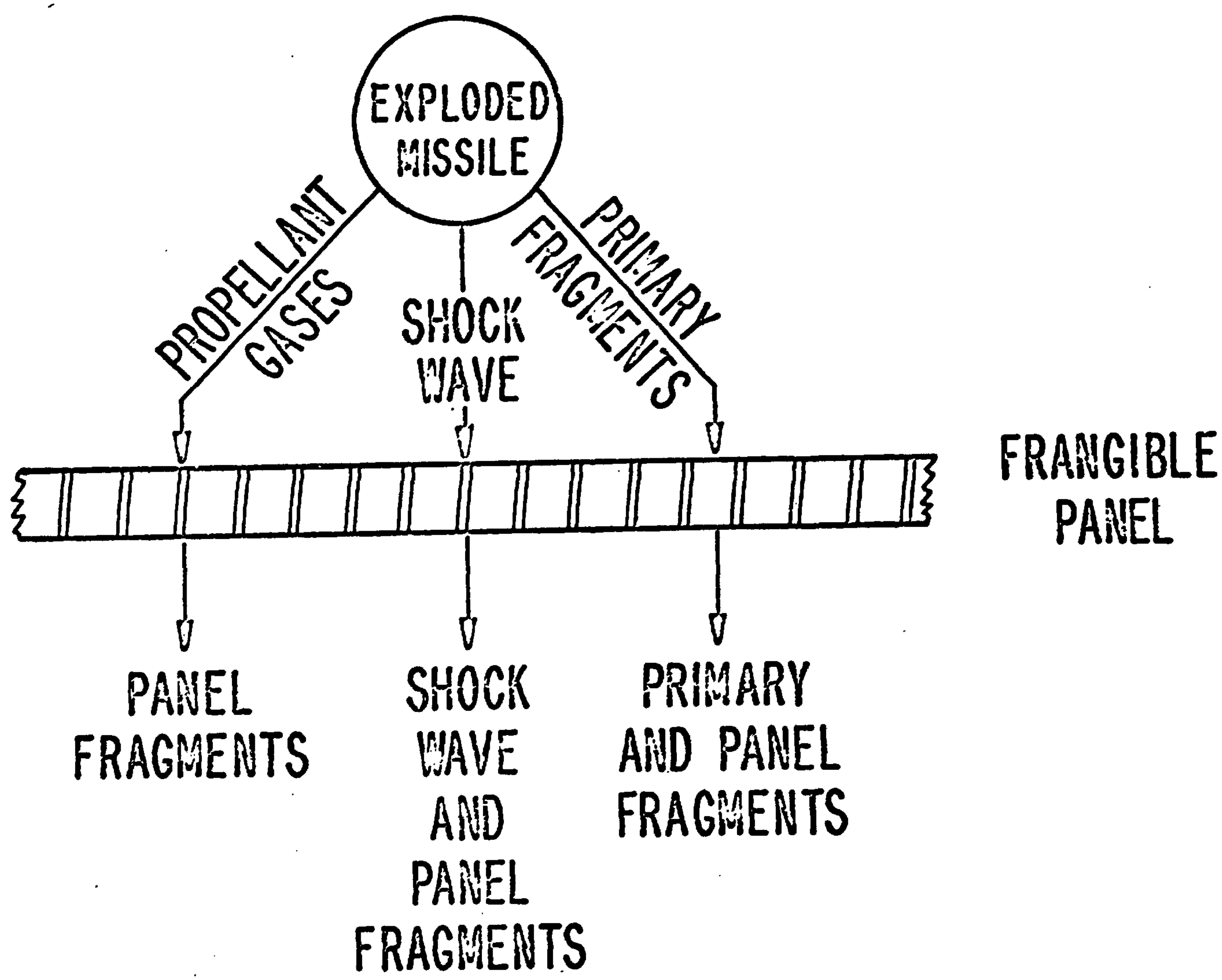
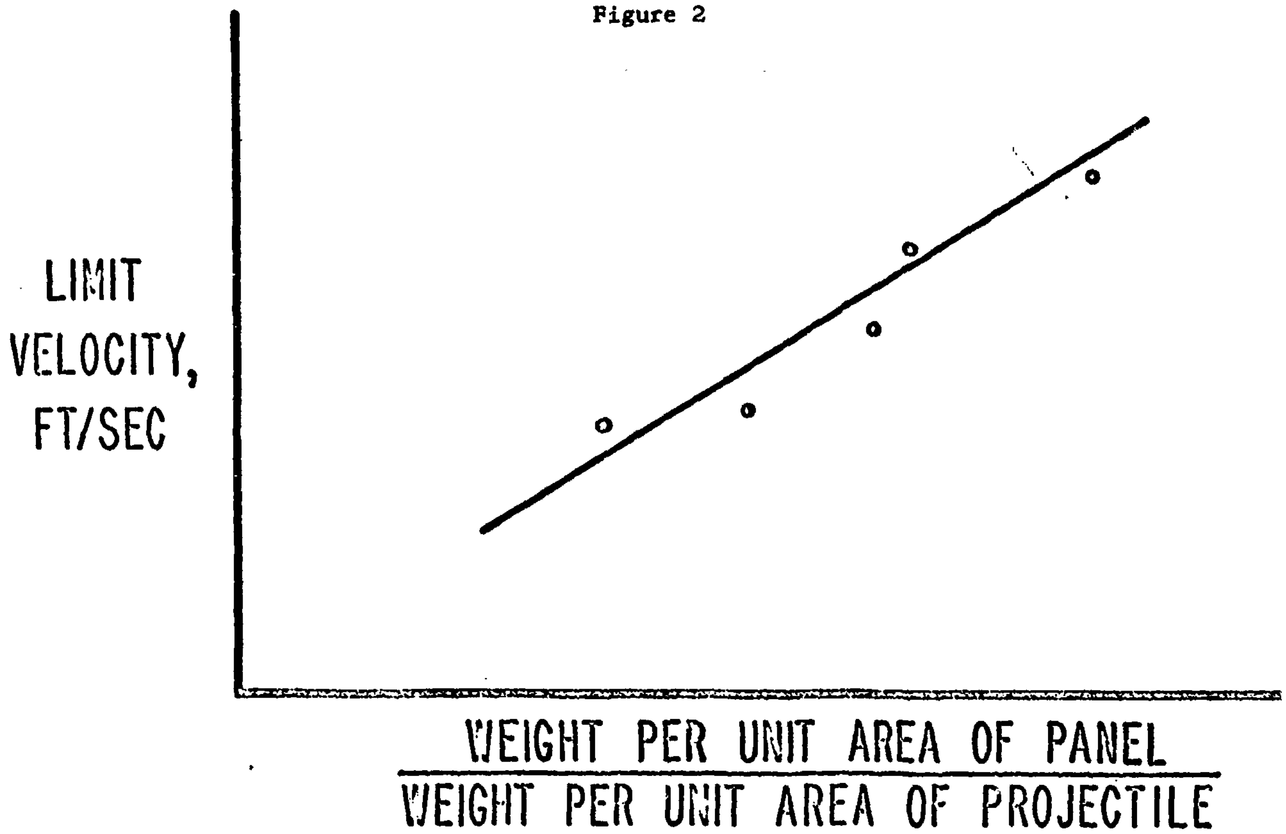
FIGURE 1

PRIMARY AND SECONDARY DAMAGING AGENTS



VELOCITY ATTENUATION

Figure 2



$V_L = 4600\ (W/A)_T/(W/A)_P$

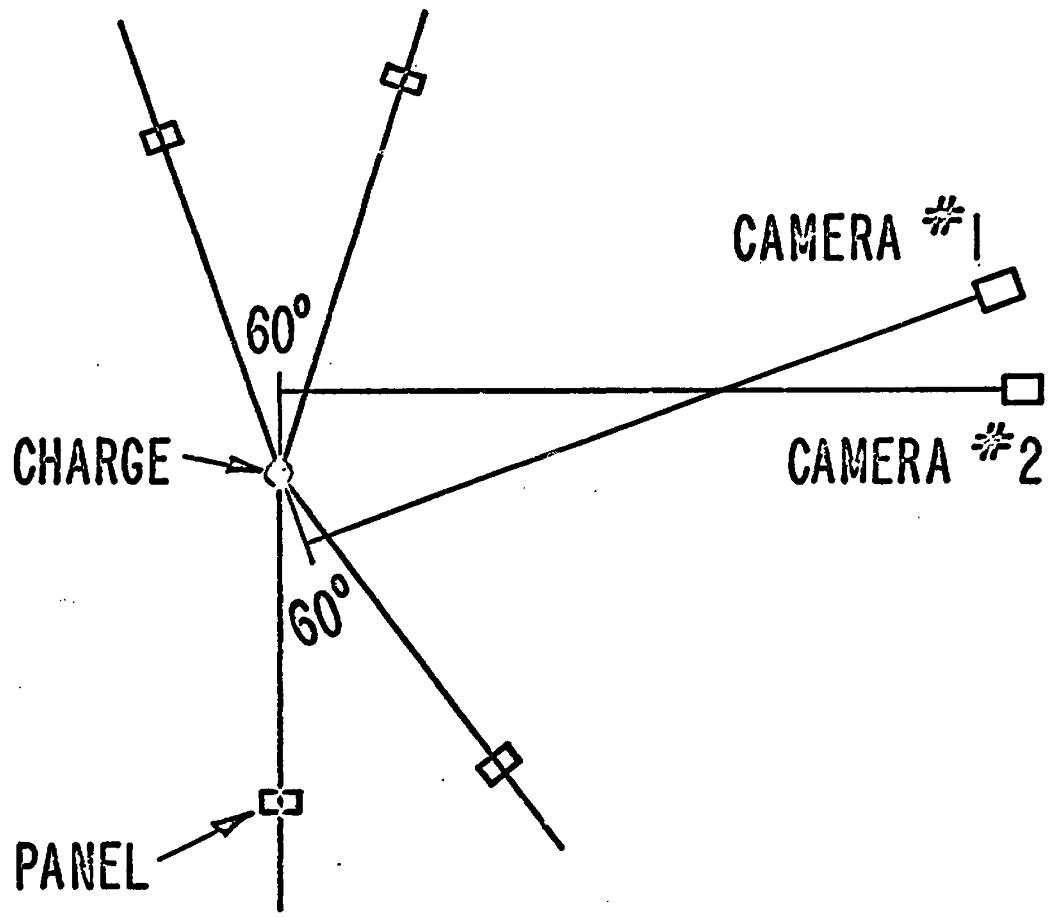
$$V_R^2 = \frac{V_S^2 - V_L^2}{1 + \alpha R}$$

When, V_L = Limit Velocity for Projectile Perforation, Ft/Sec
$(W/A)_T$ = Weight Per Unit Area of Al Honeycomb Panel
$(W/A)_P$ = Weight Per Unit Area of Projectile
V_R = Residual Velocity of a Perforating Projectile
α = 1.6, An Empirical Constant
R = Abcissa of Above Graph

5

FIGURE 3

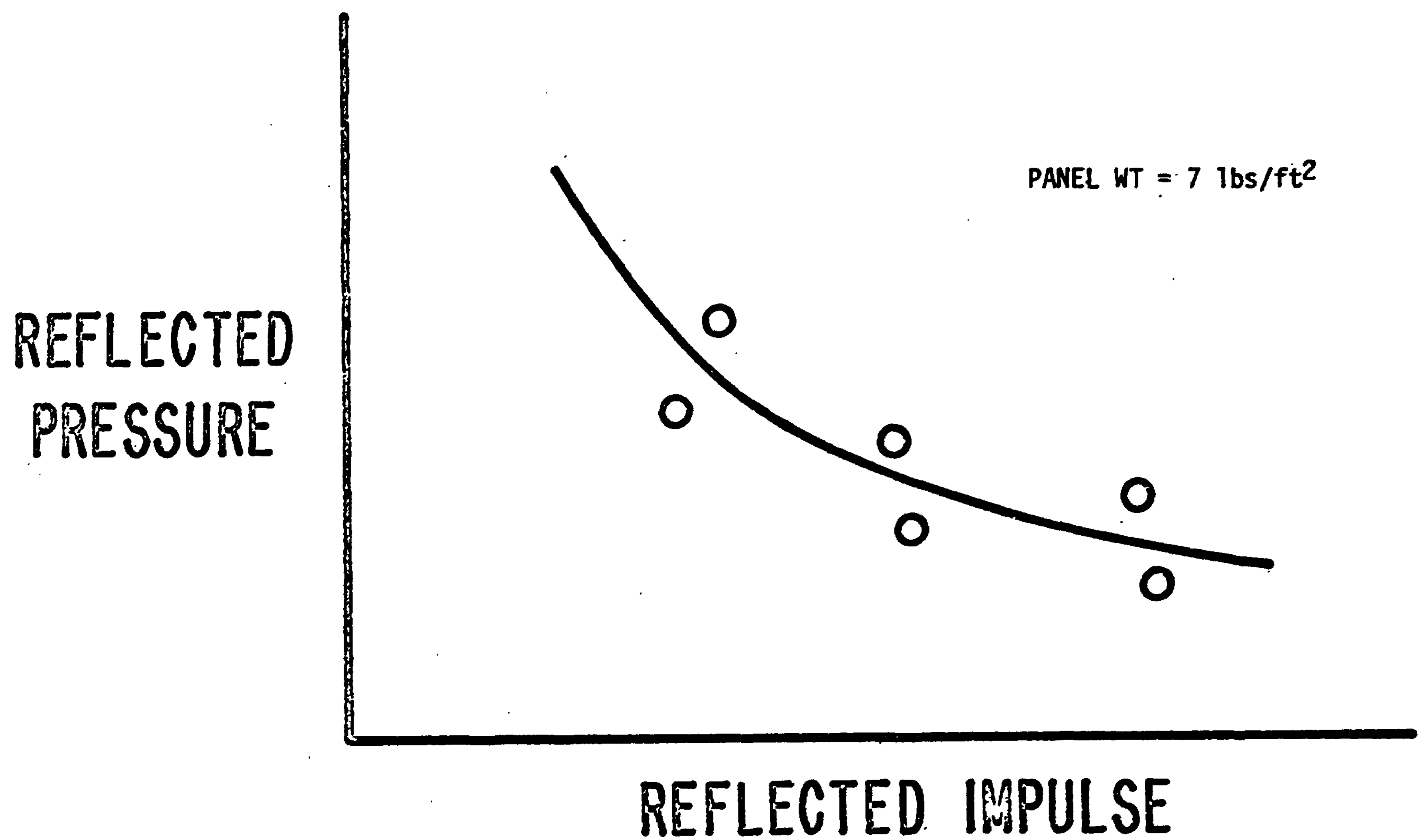
TEST FACILITY



PANELS ORIENTED AT VARIOUS DISTANCES
FROM CHARGE AT 25° LAUNCH ANGLE

FIGURE 4

DELAMINATION CRITERIA



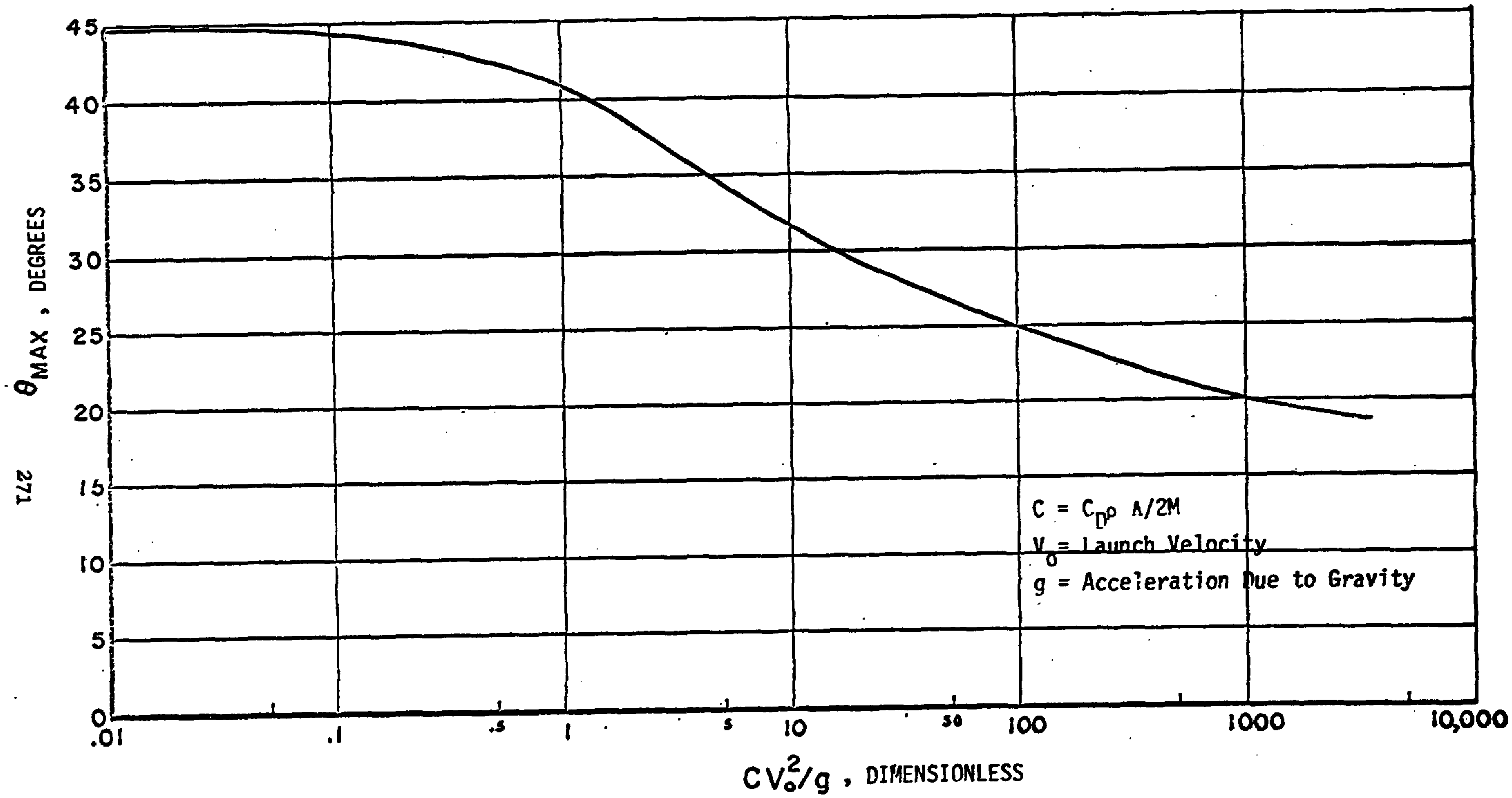


Figure 5 - Angle of Launch for Maximum Range

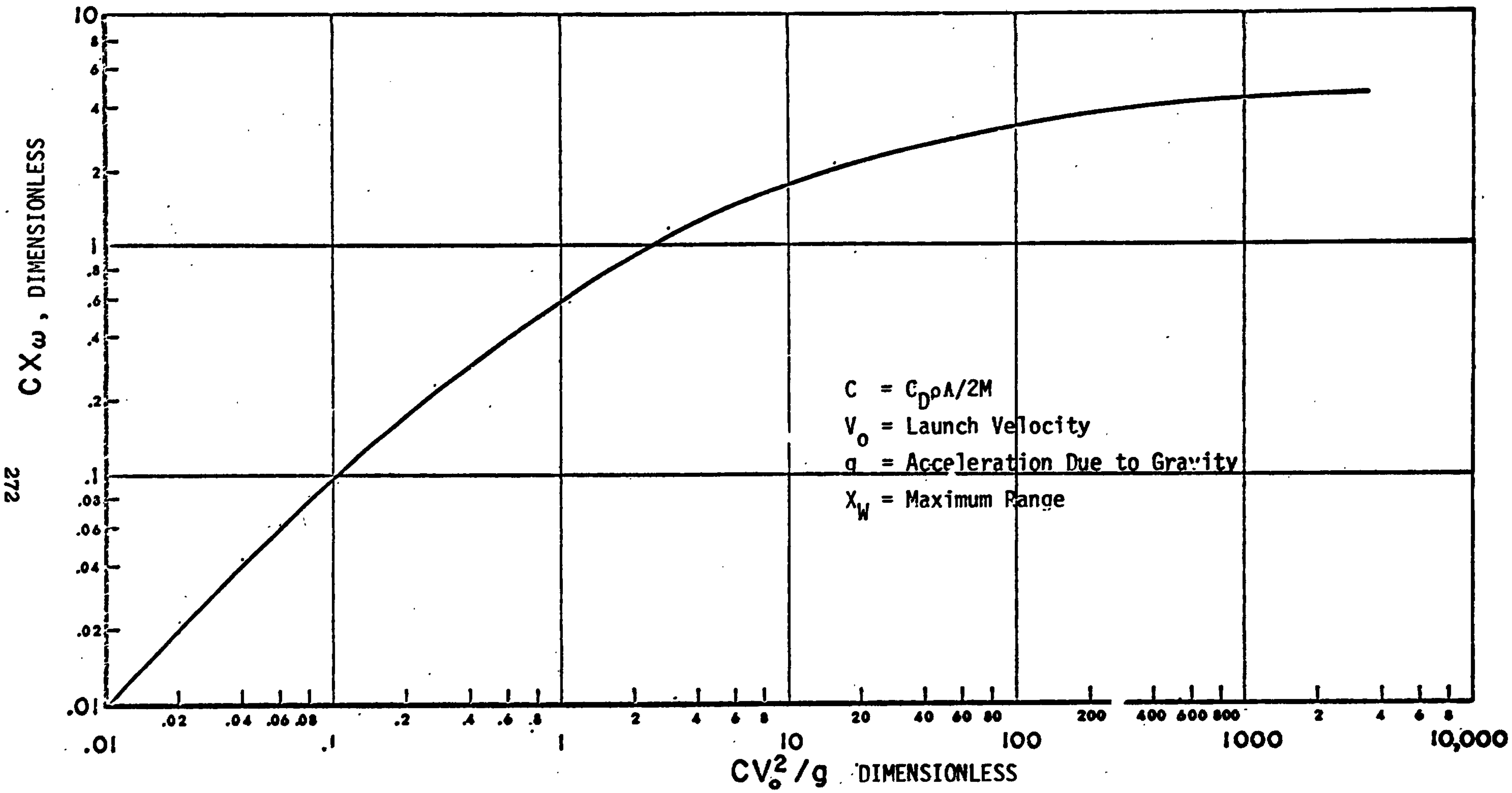


Figure 6 – Non-Dimensional Maximum Range

THE MEANING OF SIMULTANEITY OF DETONATION
WITH RESPECT TO THE APPLICATION OF
QUANTITY – DISTANCE REGULATIONS

Kenneth Kaplan
Manager, Fluid Mechanics Dept.
URS Corporation

The title of the paper is fairly descriptive except that my basic subject is non-simultaneity of detonation rather than simultaneity. The important point to be made is that explosions need not take place simultaneously in order to be the complete equivalent of simultaneous explosions – at least as far as air blast is concerned. The non-simultaneous detonation of two, or more, groups of explosives located physically close to one another can give rise to a blast wave which at some distance from the source has characteristics identical to those of the wave that would be formed if all the material exploded simultaneously. Even if the waves from two such sources did not completely coalesce, that is, did not form a single wave but rather one with two peaks and a long duration, the damaging effect on a structure or structural element of this type of wave could conceivably be as great as the effect of a single wave with higher peak pressure but shorter duration.

Perhaps the most surprising thing that I have to report is the fact that the formation of a single shock wave from two explosions takes place even if the time between the explosions is relatively long. It has long been known that "dirty" shock waves clean up, that is, that minor shock waves which follow an initial shock tend to catch up with the initial shock, merge with it, and form a single smooth shock. Within one or two charge radii of any explosive charge – even one that seems perfectly spherical and homogeneous – the shock wave formed by the explosion of that charge is very irregular and contains many secondary shocks. Shock overpressures where this occurs are on the order of some thousands of psi. At some distance from any charge – even one formed by such disparate components as shells, bombs, packing crates, and gaping holes – if all the material detonates, the shock wave will be sharp, smooth, and single. This can occur well before peak shock overpressure falls to on

the order of 100 psi. Thus the homogeneity of the source of an explosion is not especially important as far as the shock wave at some distance from that source is concerned.

It seems that the same thing can be said for two, or more than two, separate piles of explosives even when there is a significant time difference between their detonations. As a measure of what the term "significant" can mean, for stacks of explosives of some 5000 lb located in adjacent storage bays separated by a "substantial" dividing wall, small-scale tests indicate that delay times can be as large as 30 and possibly 50 or more msec, and the shock wave form will still be single and sharp-fronted at the "inhabited building" distance given in various regulations. Furthermore, the wave will have the same characteristics as one from 10,000 lb of explosives if two bays are involved, or 20,000 lb if four bays are involved. This means that if there is a significant possibility of propagation of explosion from one bay to the next, even at late times, quantity—distance regulations must take into account all the explosive present and not just the amount present in one bay. While 30 msec does not sound like a very long delay time, it would be more than ten times the time needed for a shock wave from one charge to arrive at the location of a second. It would be almost five times the estimated time needed for spalls from a concrete dividing wall to begin to arrive at a second charge in an adjacent storage bay.

These conclusions are based largely on the results of a limited series of tests with small charges (on the order of ¼ lb).* In these tests two hemispherical charges were placed within two simulated storage bays separated by a very substantial wall of steel, which did not spall or break. In front of the bays was placed a model of a single revetted barricade. At some distance from the model storage configuration, pressure sensors were placed. Charge delay times were set by connecting the two charges with varying lengths of primacord.

*Other far more comprehensive test programs involving charges in somewhat different geometries than the geometry reported here (notably a program carried out by Mr. J. Pittman of the U.S. Naval Ordnance Lab) confirm the general results of this limited program.

A view of the experimental installation is shown in Fig. 1. In the foreground is the model storage bay (in which a number of detonations have already taken place – note the bulging of the side walls); in the middle distance are shown the locations of the pressure sensors. The small portable devices on the left side of the plywood flooring contained trigger gauges which were used to start sweeps of oscilloscopes mounted in the truck in the rear of the picture. In this view, two hemispherical charges can be seen along with primacord connecting them.

Figure 2 is another view of the installation which better shows the location of the pressure gauges in the center of the picture within the rectangles of tape The model storage installation is in the background.

Figure 3 is the close-up view of the storage configuration again showing the hemispherical charges and the primacord connecting the two.

Figure 4 shows the scale of the model storage configuration, the shape of the single revetted barricade, and the size of the charges relative to that barricade.

The locations of the pressure gauges used is shown in Fig. 5. The nearest gauge was 14 ft from storage configuration, the most distant gauge, 31½ ft.

In this series of tests, delay times were varied between approximately 0.3 and 3 msec (time scale to 500 lb of explosives in each storage bay is by a factor of approximately 27). In addition to the tests with two charges, a number of tests with single charges were made.

For delay times ranging from 0.3 msec to about 1 msec, only a single pulse was observed at all measuring stations. For delay times of about 3 msec, a double pulse was observed. With the shorter delay times, the single pulse measured was identical to that which would have been expected had both charges gone simultaneously – or rather had both charges been combined into one. This is illustrated in Fig. 6, which shows oscilloscope traces from two tests, one with a single charge, the second with two charges differing in detonation time by 0.275 msec. Note that the pulses are virtually identical except for

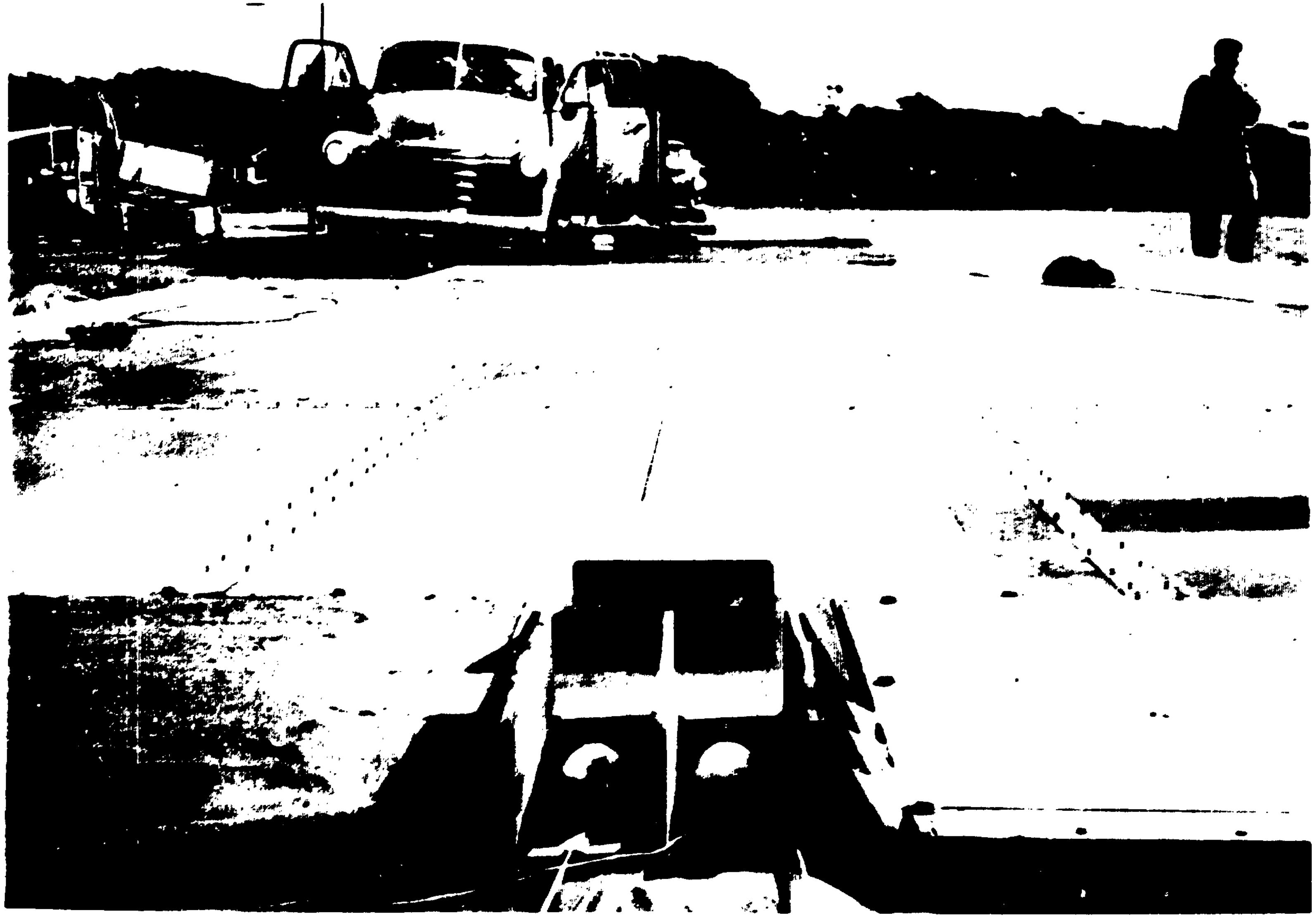


Fig. 1. View of Experimental Installation from Behind Model Storate Bays

Fig. 2. View of Pressure Gauges and Model Storage Bays

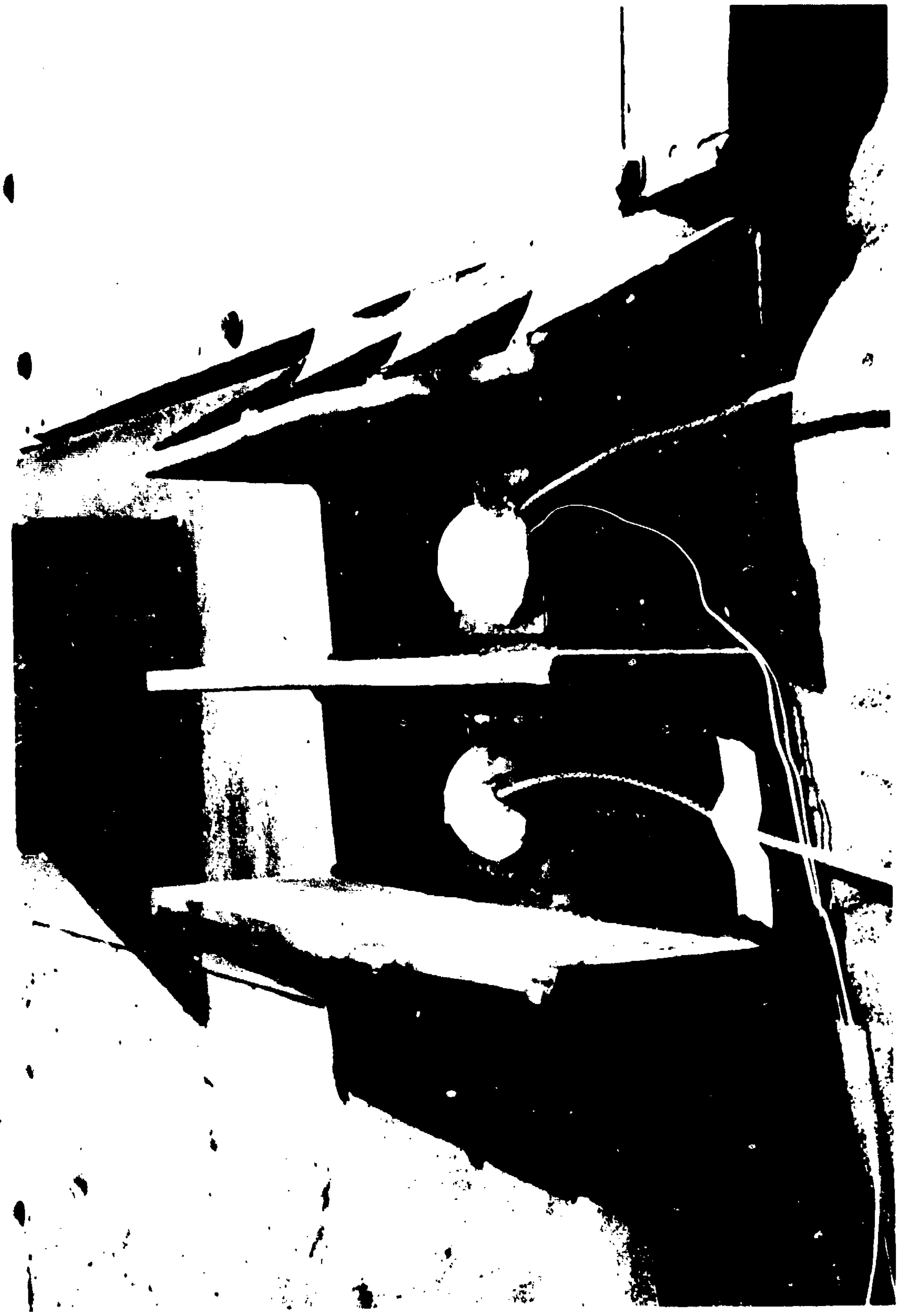


Fig. 3. Closeup View of Model Storage Bays

Fig. 4. View of Model Storage Bays, Revetment, and Hemispherical Charges

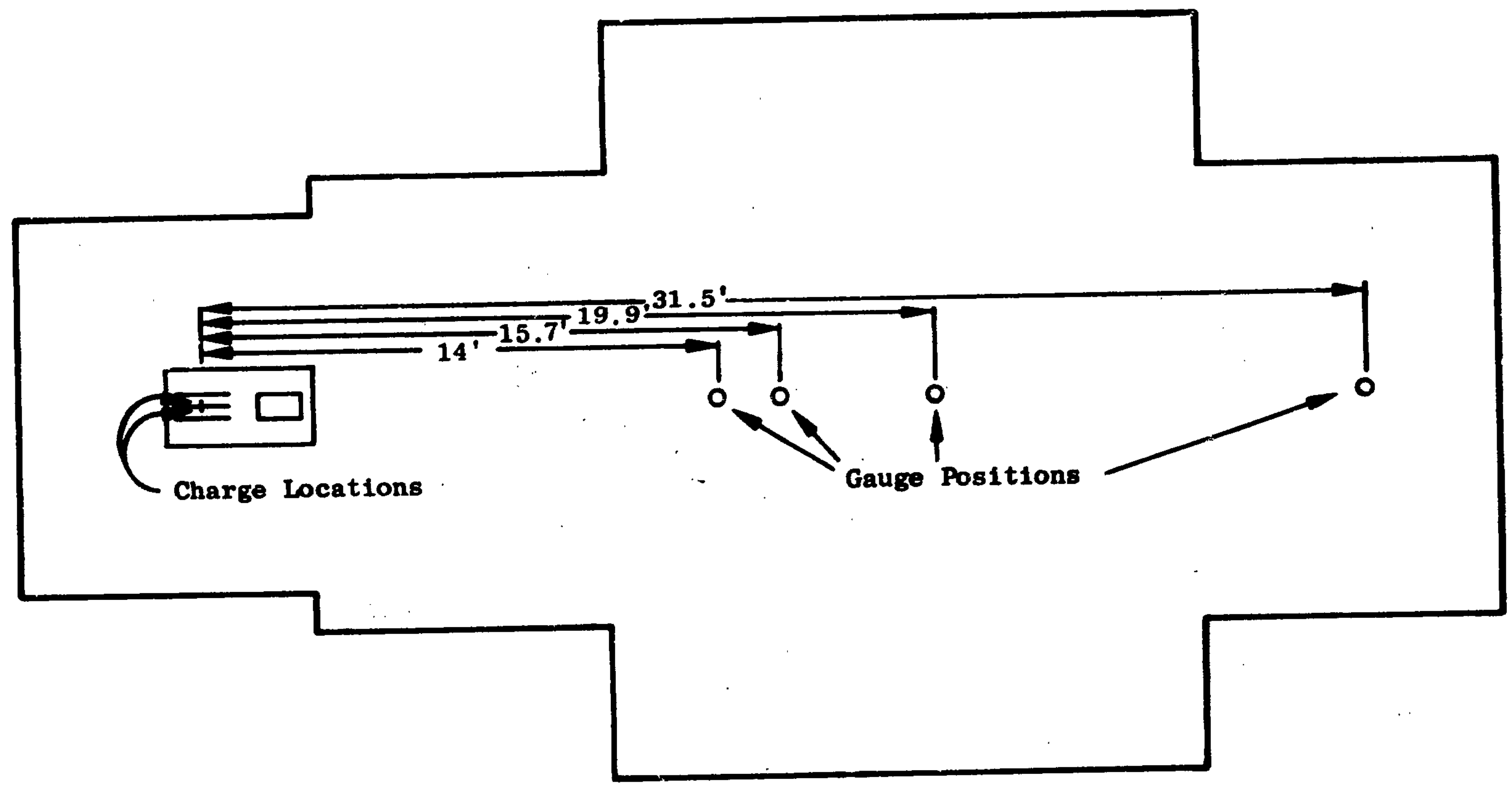
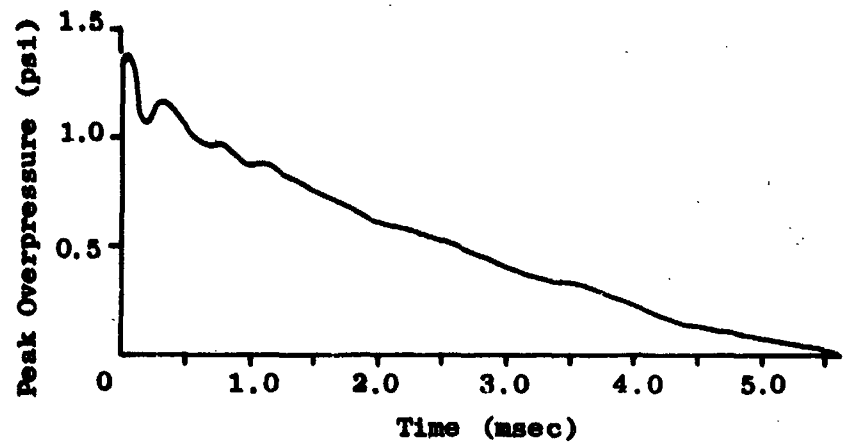
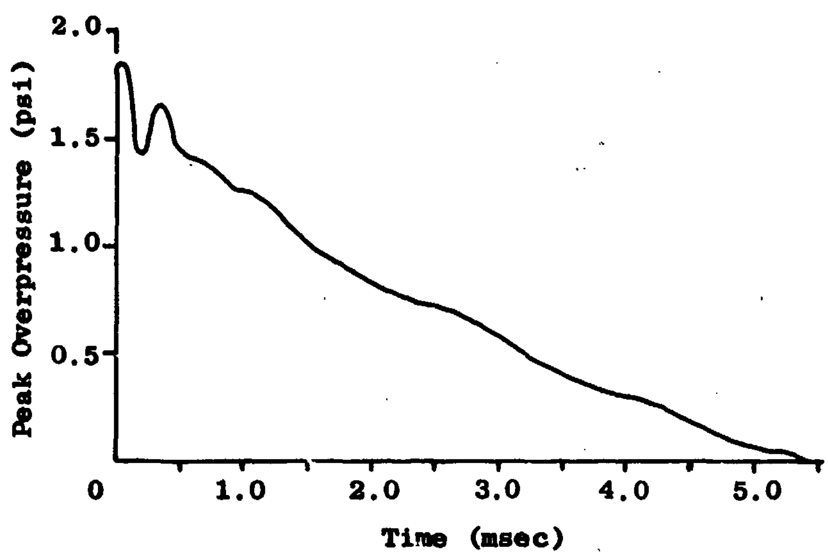


Fig. 5. Sketch of the Model Showing the Charge Location and Gauge Positions



Test No. 8, Single-Charge Peak Overpressure 1.4 psi



Test No. 14, Two Charges (0.275 msec delay) Peak Overpressure 1.8 psi

Fig. 6. Sample Traces from Single-Charge Test No. 8 and Two-Charge Test No. 14, 19.9-ft Gauge Location

the fact that the second pulse indicates a peak overpressure of 1.9 psi, while the first pulse has a peak overpressure of 1.4 psi. The measurement in each case was made at the measuring station about 20 ft from the storage configuration.

The effect is further illustrated in Fig. 7, which is a plot of the averages of peak pressure measurements made at the four pressure-recording stations. (The measurements themselves are tabulated in Table 1.) The figure shows the peak pressure measurements at the four stations from the single-charge experiments, and from all the double-charge experiments — whatever the delay time — which gave rise to single pulses. Also shown in the figure is a line constructed by multiplying the ground distances for the single-charge points by the cube root of two. By this means the single-charge results can be used to predict the peak pressure from another single charge weighing twice that actually used. The closeness of the scaled line and the points from the double charges with delays up to 1 msec between their detonations is apparent.

A photograph of one of the oscilloscope traces of the only double pulse recorded is shown on Fig. 8. The peak pressure of the first pulse at all measuring stations was essentially the same as that recorded with the single charges.

Although the two pulses in Fig. 8 are separated, with a somewhat shorter delay time the second pulse would have partially encroached on the first. In effect the two pulses might have become one and been characterized by a relatively low peak overpressure but also by a long duration. The influence of duration on structures and structural elements is shown on Fig. 9. In that figure the resistance of a structural element required to avoid its failure r_y relative to the peak overpressure p_m of an incident pulse is shown as a function of various parameters, including — on the abscissa — the duration of loading divided by the natural period of the element. For any one element it is clear that an increasing duration for a given peak overpressure results in a strong increase in the resistance required to avoid failure.

The scaling used to interpret the results from these ½-lb charges in terms of results with 5000-lb charges is the same kind used quite successfully

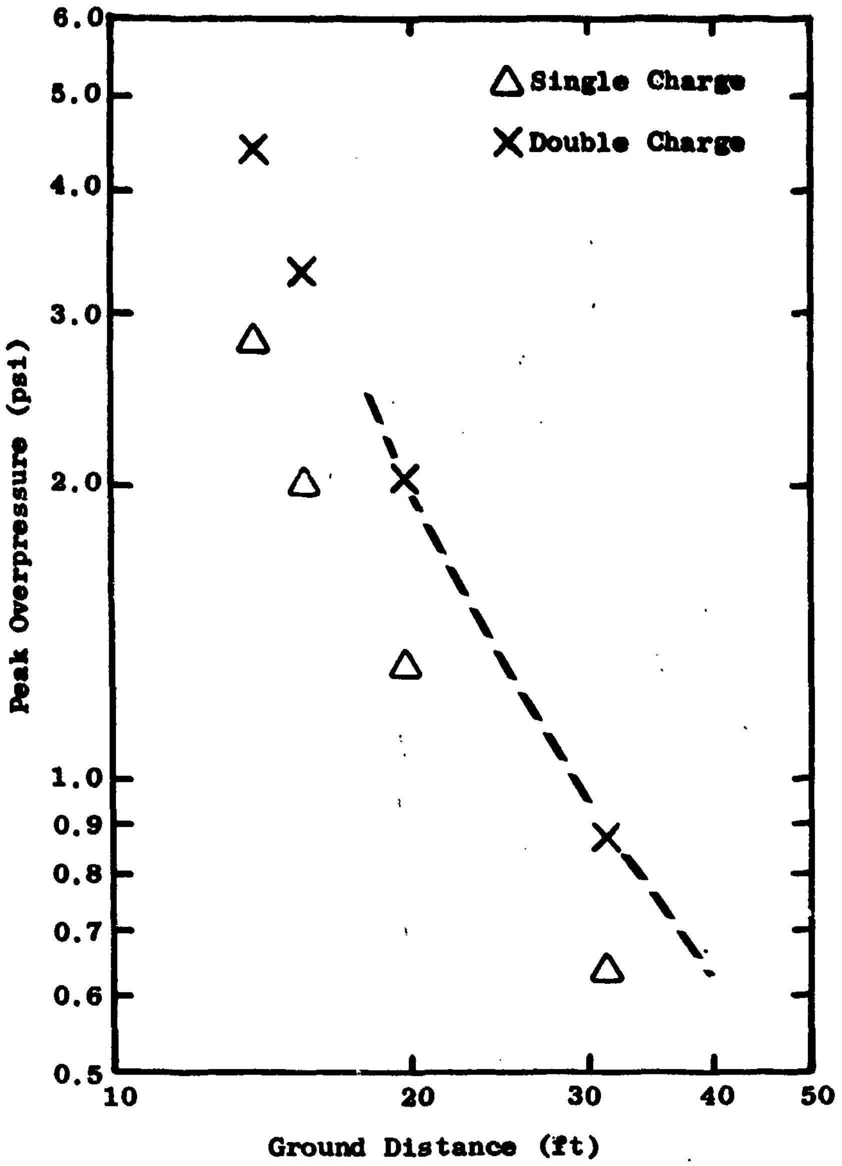


Fig. 7. Peak Overpressure vs Ground Distance for Tests with a Single Charge and Tests with Two Charges (dashed line represents data for single 1/2-lb charge)

Table 1

SUMMARY OF TESTS

Test Number	Test Condition		Peak Overpressure (psi) at the Several Gauge Distances (ft)			
	No. of Charges	Delay Time (msec)	14	15.7	19.9	31.5
7	1		2.8	—	1.4	—
8	1		2.8	1.9	1.4	0.7
16*	1		2.8	2.1	1.2	0.6
18	1		2.8	2.0	1.2	0.6
10	2	0.275	4.2	3.5	2.2	0.9
12	2	0.275	4.6	3.1	2.0	0.9
13	2	0.275	4.2	3.1	1.8	0.7
14	2	0.275	4.0	3.2	1.8	0.7
15	2	0.825	4.7	3.5	2.1	0.9
17**	2	0.378	4.6	3.7	2.3	1.1
19	2	0.99	4.5	3.1	2.0	0.9
20	2	2.73	***	***	***	***

* Charge placed outside model.

** Two charges placed outside model 65 in. apart.

*** All pulses had double peaks.

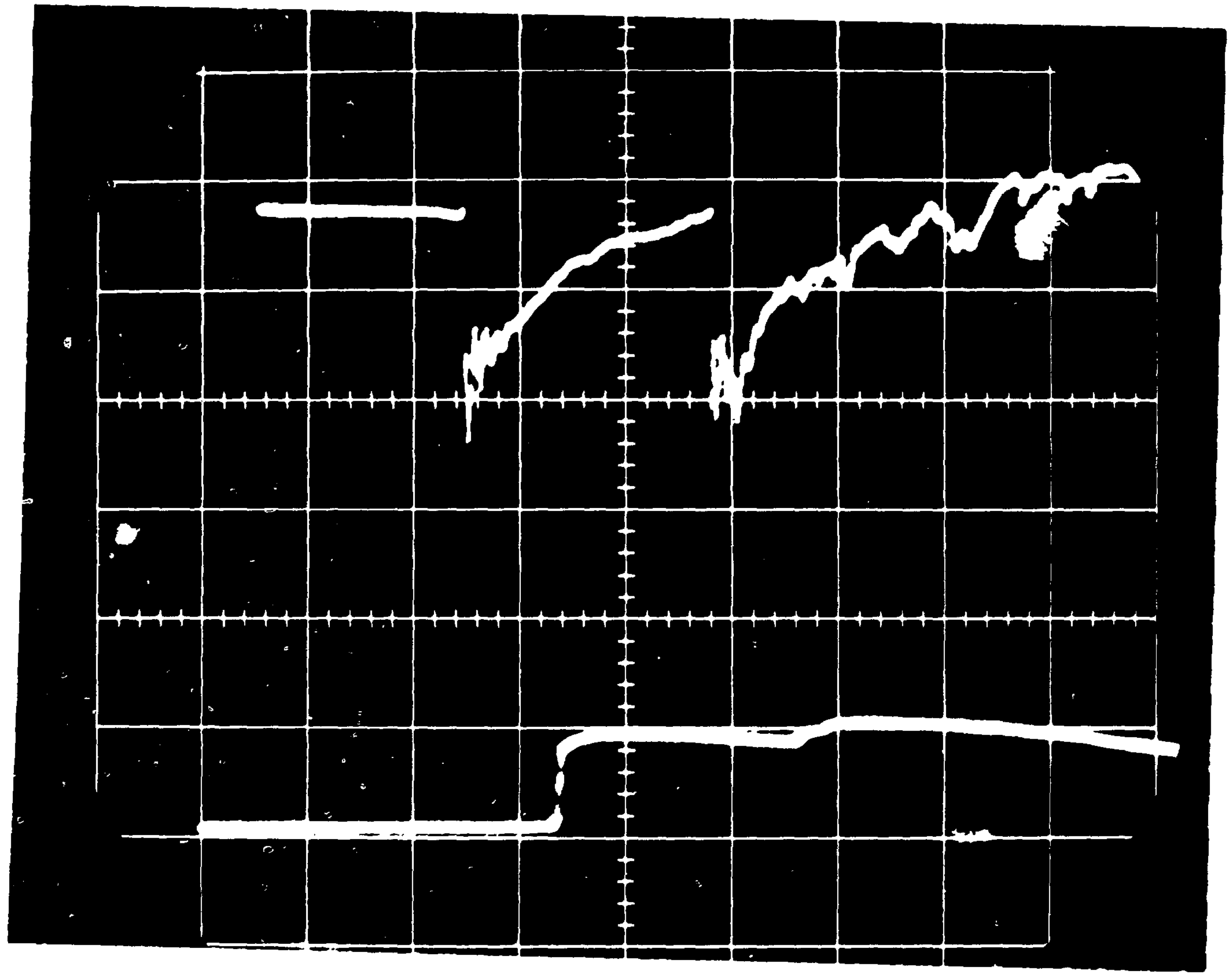


Fig. 8. Oscilloscope Trace of Double Pulse. The pulse is in the upper portion of the photograph, positive downward.

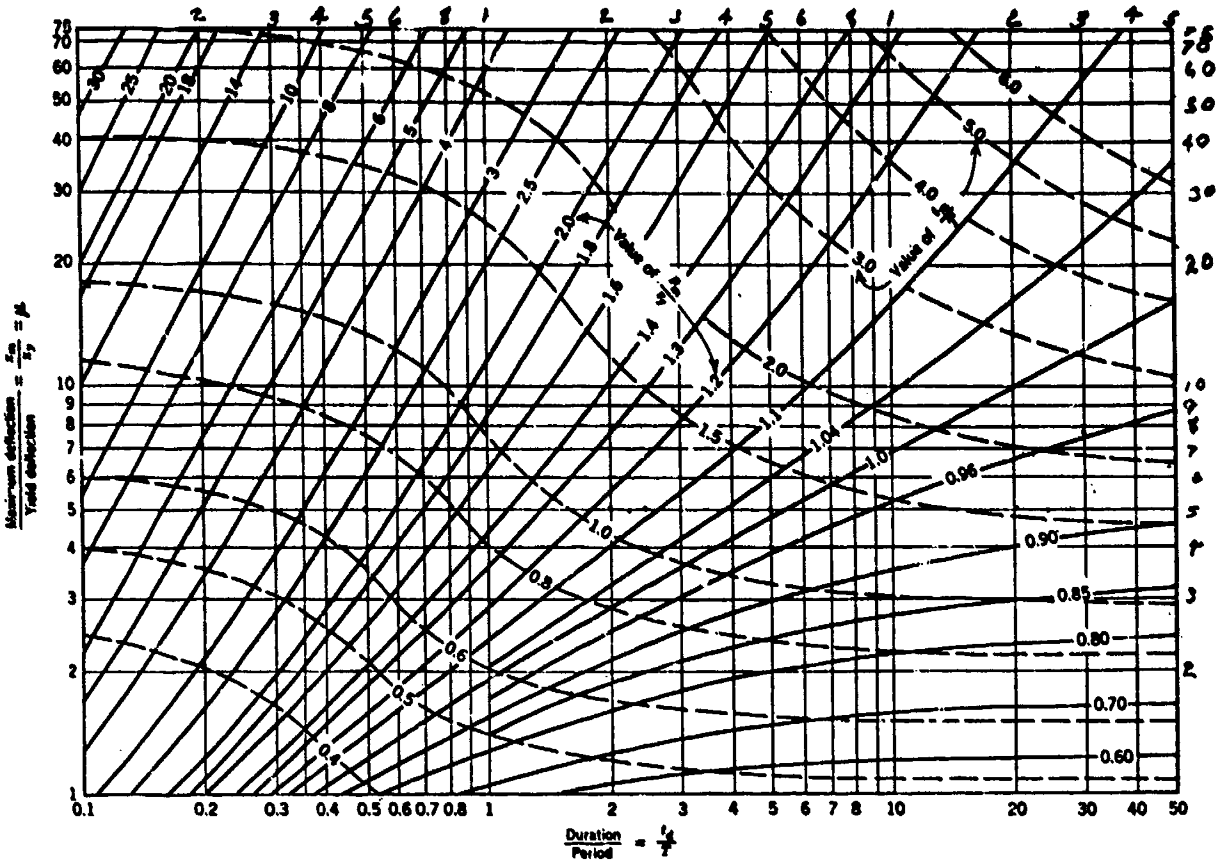


Fig. 9. Response of Shock Loaded Structural Elements. p_m = peak overpressure; r_y = structural resistance.

to predict various air blast parameters for high-explosive charges of up to 500 tons from the results of tests with pound-size charges. It is known as "cube root scaling" and its influence on various air blast parameters is shown in the following two equations.

$$p_m = f_1(d/W^{1/3})$$

$$t/W^{1/3} = f_2(d/W^{1/3})$$

where d = distance

W = charge weight

p_m = maximum overpressure

t = time

The most important implications are that at a particular "scaled distance" (that is, a particular value of $d/W^{1/3}$), peak overpressures from two charges of different size are identical, but times (e.g., positive durations) increase as the cube root of the charge weight.

Air blast parameters scale very well; other factors — in particular structural response — are much more difficult to scale and no attempt was made in these tests to scale structural response. The results of these tests are being further verified in a full-scale testing program now being conducted under the sponsorship of the Armed Services Explosive Safety Board.

An additional result of these tests was some evidence that the single revetted barricade has essentially no effect on the blast wave measured at any of the measuring stations. In some of the tests the charges were removed from the storage configuration, that is, they were not behind the single barricade. In these tests the pulses were essentially identical to those recorded when the charges were behind the barricade. There were, however, no pressure gauges located close enough to the barricade to delimit its area of effectiveness.

RESPONSIBILITIES OF THE NEW DEPARTMENT OF TRANSPORTATION WITH RESPECT TO EXPLOSIVES AND OTHER DANGEROUS ARTICLES

by
Mr. Gordon Rousseau
Department of Transportation
Washington, D. C.

The Department of Transportation came into being on 1 April of this year. I represent one of the segments that was transferred from the Interstate Commerce Commission. I want to say at this time that the Interstate Commerce Commission continues to exist as an economic regulatory agency. Only its safety functions were transferred to the Department.

In the Interstate Commerce Commission, the Bureau of Operations and Compliance included an organizational segment identified as the Section of Explosives and Other Dangerous Articles. This Section was transferred into the Office of the Secretary of the new Department and is now called the Office of Hazardous Materials. In a series of figures to follow, I'll give you an idea of the general organizational breakdown. You will see some very firm plain lines drawn between various components, but they are probably the only such clear and straightforward lines that exist right at the moment, especially as regards the field of hazardous materials transportation.

Figure 1 is a general breakdown of the overall organization. I will go into more detail discussing the administrative and technical staffs. This is what I will mostly dwell on but the figure does give you a general idea of what constitutes the Department. One important point to note is that each administration, the Coast Guard and the St. Lawrence Seaway Development Corporation maintains its independent operational responsibilities. These are organizational, functional lines from the Secretary down to the various components.

In Figure 2 we see the two staffs of the Secretary as they are broken down. Here again, I don't think I have to elaborate. All the Assistant Secretary positions, the Secretary, the Under Secretary, and the heads of the component groups are Presidential appointments. The Commandant of the Coast Guard is appointed for a given time period, the other appointees, of course, serve following the wishes of the President.

Figure 3 depicts the organization within the Office of the Assistant Secretary for Research and Technology. On the right of the slide you see the office I represent, the Office of Hazardous Materials. I should mention that throughout the Assistant Secretary's office, staffing at the moment is very minimal. Under the Assistant Secretary for R&T, Mr. James E. Densmore now acting in that capacity, there is only one office that is somewhat staffed; we call it OHM for short, the Office

of Hazardous Materials. R&D, Noise Abatement, and Transportation Planning have practically no staffs as yet.

To give you an idea of the type of problems we're organizationally running into, our office is now conducting a literature study for the Secretary on the subject of air pollution by jet aircraft. Our office's responsibility, as many of you know, is the administration of rules for the safe transportation of hazardous materials. As you can see, the subject of jet engine air pollution is somewhat outside our normal scope of activity.

The Office of Hazardous Materials is divided into three Divisions: the Safety Standards Division, the Technical Division and the Operations and Training Division. What is probably new for this group to hear is the building of a technical staff. We presently have four people on this staff and hope to soon have several more. Presently, we have a health radiation physicist, two mechanical engineers and a pipeline engineer. Soon we hope to have in addition, another mechanical engineer, a radiological engineer, a packaging engineer, and a chemical engineer.

The role of this office is intended to be primarily one of coordination and review within the Department. It does not have, for instance, its own field staff, it does not as such enforce the hazardous materials regulations, but provides guidance and advice to the Department in these areas. It is the focal organization that will be working with many of you in various problems relating to transportation. Particularly, with reference to the Department of Defense, the organization that we will be primarily dealing with is MTMTS, which the Department of Defense itself is trying to set up as a coordinating point within its structure. I make a specific mention of it here because it appears that this is a point many are having some difficulty in understanding; but MTMTS is our reference point in dealing with many of you people here regarding specialized problems in transportation or the development and improvement of regulatory controls.

One more thing I might add is the manner in which we function with the various model transportation components of the Department. The system operates through an organization called the Hazardous Materials Regulations Board. This is a high level board chaired by the Assistant Secretary for R&T. Its members are the Federal Railroad Administrator, Federal Highway Administrator, Federal Aviation Administrator, and the Commandant of the Coast Guard. The Secretary of the board is Mr. Wm. K. Byrd who was scheduled to address you today but was detained in Washington on some very pressing business. Mr. Byrd is the Director of the Office of Hazardous Materials. The Department's General Counsel's office provides legal aid. Needless to say that some of these assignments will be delegated to a certain degree, but this will be the functioning unit that will be amending the present regulations, that will be doing the work of coordinating regulatory changes for all modes of transportation.

The first and second points in Figure 4 represent primarily what the Office of Hazardous Materials is doing. I like to think of the third point as more of an operational media, and it is in this area that the various administrations are to take a very active role. I refer principally to the numerous carrier oriented requirements, rail, highway, air and water, where the modal representatives have definite expertise and will be exercising their particular responsibilities. Remember, however, that even though the Office of Hazardous Materials will be handling items such as packaging rules, shipment identification, hazardous materials identification which are inter-modal in nature, it still will not have any direct enforcement function.

Where we plan to go with what we have is summarized in Figure 5. The emphasis on accident study and prevention is accentuated by the fact that we have within our organization a group called the Operations and Training Division which is presently concentrating on accident reporting and evaluation. As concerns reclassification, we plan to most probably contract out for a full scale study on the overall classification of hazardous materials that are or should be covered under DOT regulations. As concerns labeling, many of you are aware that a study has been going on since 1954, under the auspices of the United Nations, to come up with an international labeling system. We are very near to the point of proposing this new system. A draft has been prepared and forwarded to the Department's General Counsel. Regarding packaging, I can sum it up by saying that the work being done on radioactive materials packaging is representative of what we hope will happen to the hazardous materials packaging field as a whole. We are moving more and more towards performance standards. We hope to not define so explicitly how many nails are required in a given specification wooden box, but rather what the wooden box is expected to withstand in transportation. I do not want to give you the impression that structural specifications will be abandoned, but that we will be giving more weight to performance.

The keynote of this new office will be technical research. The biggest problem we have now to get started as is everyone else's, is money. The Secretary has told us to get certain things done. On the other hand, Congress holds the purse strings.

We must realize, despite all this planning that we are faced with many basic problems that no amount of regulation can correct. We call it human error. No system of regulation can get away from this. We are faced with it no matter how technical, scientific, or objective we want to be. We still have the problem of caps on bottles not being screwed on tightly. Thank you.

DEPARTMENT OF TRANSPORTATION

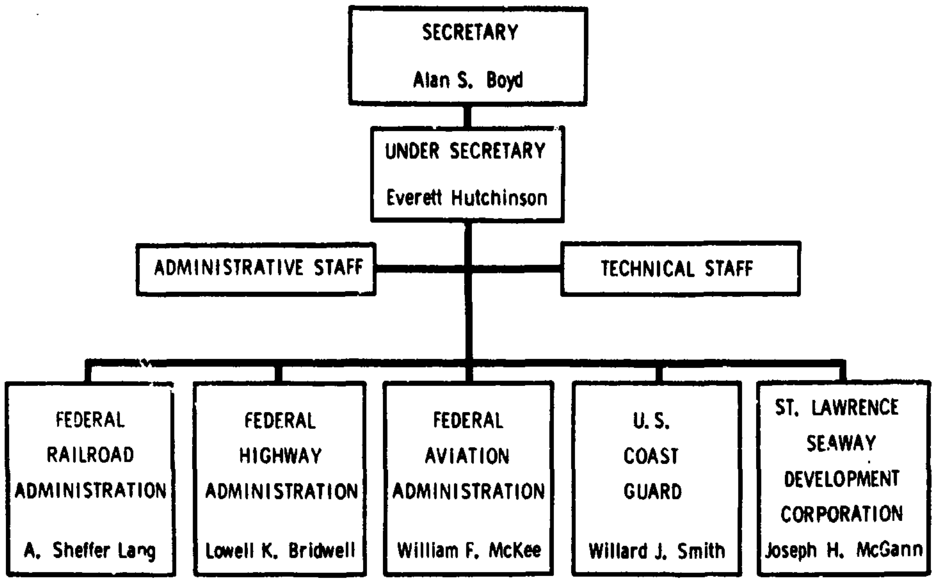


Figure 1

DEPARTMENT OF TRANSPORTATION

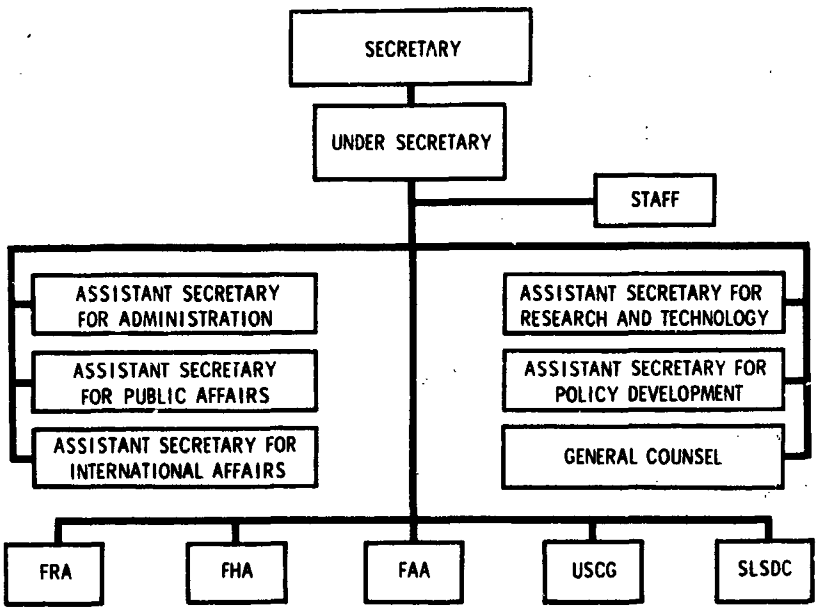


Figure 2

DEPARTMENT OF TRANSPORTATION

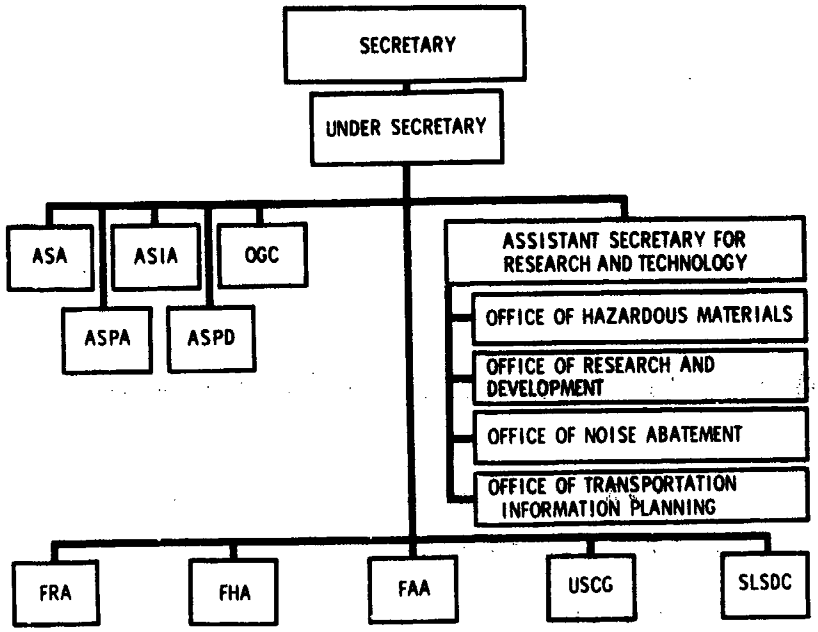


Figure 3

REGULATIONS PROVIDE:

1. PACKAGING RULES
2. PACKAGE IDENTIFICATION
3. SHIPPING CONTROLS

Figure 4

MAJOR REGULATORY CHANGES

1. MORE EMPHASIS ON ACCIDENTS
2. RECLASSIFICATION
3. LABELING
4. PACKAGING
   a. More types
   b. More flexibility
   c. Definition of criteria

Figure 5

AIR FORCE HIGH DENSITY MODULAR STORAGE OF BOMBS IN SOUTHEAST ASIA

by
Mr. P. H. Schuyler
Headquarters, U. S. Air Force
Norton AFB, Calif.

A status report on Air Force high density modular storage of bombs in Southeast Asia was given. Summary of recent Air Force test "BIG PAPA" was given also. Full details of this test will be available in an official Air Force Weapons Laboratory report. For further details contact Mr. Schuyler at Norton Air Force Base, California, Code AFIAS-G2.

LARGE SCALE PROPAGATION TESTS RECOMMENDED NON-PROPAGATING DISTANCES FOR AN, ANFO, AND DYNAMITE RECEPTORS

by
Mr. F. A. Loving
E. I. du Pont de Nemours & Co.
Wilmington, Delaware
&
Dr. Robert W. Van Dolah*
Bureau of Mines
Explosives Research Center
Pittsburgh, Pa.

*(A short film was presented by Dr. Van Dolah at the beginning of the presentation)

The objective of the test program you have witnessed in Dr. Van Dolah's presentation was to establish safe separation distances for ammonium nitrate (AN) and ammonium nitrate fuel oil (ANFO) receptors from high explosive donors. The chore of extrapolating the test data to provide the required separation tables fell upon an ad hoc industry committee chaired by Mr. H. W. Backes, Monsanto Chemical Co., St. Louis, Mo. The industry members of the Committee comprised Dr. W. J. Taylor, Atlas Chemical Industries, Wilmington, Delaware; Mr. Sam Porter, Explosives Engineering consultant, Arlington, Virginia; and Mr. F. A. Loving, du Pont Co., Wilmington, Delaware. The group was assisted and advised by the authors of the U. S. Bureau of Mines reports of the test program--Dr. R. W. Van Dolah, Mr. F. C. Gibson, and Mr. J. N. Murphy, U. S. Bureau of Mines Explosives Research Center, Pittsburgh, Pa. I should like to briefly summarize the extrapolation problems facing this group and the basis for the final recommendation produced.

One problem is obvious immediately in a plot of the data from the test shown in Figure 1. The experimental 50% propagation points for the charge weights tested did not support the cube root scaling law usually employed in tables of distance. A number of explanations were considered. One might first question the validity of cube root scaling in propagation tests. It is certainly well documented that peak pressure scales in accordance with this law. However, blast impulse scales differently, and it would be surprising if missile velocity over large gaps would obey strict cube root scaling. A great deal of small scale testing with dynamite and commercial explosives had indicated that cube root scaling was valid. However, in much of the early work of this type, only the donor charge was scaled to large charge weights; and the receptors were small. Since the probability of initiation is clearly a function of receptor size where missiles are involved, one disturbing question was

whether or not standard propagation tables such as the American Table of Distances (ATOD) intermagazine spacings were properly drawn. The Barksdale test program only evaluated dynamite receptors at one distance; consequently, experimental shots at another size were undertaken by a du Pont laboratory. The results are shown in Figure 2. Our tests at the 23-lb. level were made with a scaled geometry corresponding to the Barksdale test. The donor was again ANFO with multi-point initiation. The tests with metal missiles employed thinner metal ends, also scaled from the thickness used in the large tests. The slopes of .3 and .38 obtained appear to indicate that, at least for sensitive explosives, cube root scaling is acceptable. In fact, I have extended the non-missile line, and you will note that it predicts 50% propagation in a half cartridge sensitiveness test of about 20-in. for a half cartridge weight of about 1/4-lb. This value is typical for the grade of dynamite used.

The Committee gave some consideration to the use of a $W^{2/3}$ scaling for the less sensitive AN and ANFO receptors. While this is clearly a conservative basis of extrapolation, the resulting prediction for very large charge weights would indicate greater sensitivity for AN and ANFO than the American Table of Distances indicates for dynamite.

The American Table of Distances has provided adequate distances for many decades of use. Furthermore, the non-missile large scale test with dynamite appears to confirm the intermagazine distance of the American Table of Distances at the 1600-lb. level. Since approved magazine construction requires bullet resistant walls for dynamite storage, the non-missile propagation distance applies. The large scale test indicated a 50% propagation point for dynamite of 67-ft. Using the safety factor suggested by the Bureau of Mines data analysis; namely, an increase of 40%, one obtains 94-ft. for a non-propagating distance. The American Table of Distances prescribed 86-ft. for the separation of unbarricaded magazines containing 1600-lbs. It thus appears that the tests provide reasonably good support for at least this portion of the American Table of Distances. Figure 3 is a plot of the American Table of Distances taken from the Bureau of Mines report. It will be seen that constant cube ot scaling was not employed for intermagazine spacings at very large charge weights. Thus, some allowance was made many years ago in anticipation of larger than scaled propagation distances for very large do s and receptors.

further consideration was that the experiments were designed to model a segment of a larger mass of detonating material by means of plane wave (multipoint) initiation and aiming the donors along the direction of propaga ion of the detonation. This design certainly represents a "worst case" for extrapolation purposes.

In consequence of these considerations, our Committee chose to base recommended storage distances for AN and ANFO upon those used in the American Table of Distances (intermagazine spacings) in the following manner: the 50% propagation distances for dynamite were compared to those

obtained with AN and ANFO; factors for relative sensitiveness were obtained and applied to the American Table of Barricaded Intermagazine Distances. Since a primary objective was to provide for safe operation of field storage and mix plants typically comprising mixers, carload quantities of prilled AN and truckloads of ANFO, missile propagation was given greater weight in establishing the ratios of sensitivity. Barricaded distances for the recommended storage for the prilled AN were set at 1/6 of those prescribed for dynamite; distances for ANFO were set at 6/10 of the distance for dynamite; and finally, unbarricaded storage requires an increase of 6 times the barricaded distance. Also included in the tables promulgated is an indication of minimum barricade thickness required. These thicknesses are scaled from the test thicknesses employed at Barksdale with the cube root of the charge weights.

The tables obtained have been adopted by the National Fire Protection Association (NFPA) as a tentative standard for consideration in industry. Subsequent review by many companies and agencies concerned indicates that the prescribed distances and barricade thicknesses are acceptable as permanent standards. The Committee further undertook to provide explanatory notes and advice on the application of the tables to typical situations. Examples were added prescribing treatment of combined masses of material where propagation could occur between two or more masses. Please note that this publication is a tentative standard and hence subject to further revision. Your suggestions for revision are solicited and should be forwarded to the NFPA by September 11, 1967. Copies of the tentative standard can be obtained from the NFPA, 60 Batterymarch Street, Boston, Mass. 02110 for 60¢ per copy.

Two examples used in the NFPA tentative standard are illustrated in Figure 4. Potential donors are the material in and near an ANFO mixer and the product being accumulated in trucks. Without a barricade, either of these donors can initiate the AN rail car as well as each other, and the potentially explosive storage equals the sum of all three masses. The FGAN is considered one half as potent as ANFO, making the total explosion potential 132,500 lbs. With the AN car barricaded, the donors considered separately or jointly will not initiate the AN and the explosion potential is reduced to 82,500 lbs.

Figure 1

PLOTS OF S_{50} VALUES VERSUS CHARGE WEIGHTS

From US BUREAU of MINES Report of INVESTIGATION 6903
by R.W. Van Dolah, F.C. Gibson, and J.N. Murphy.

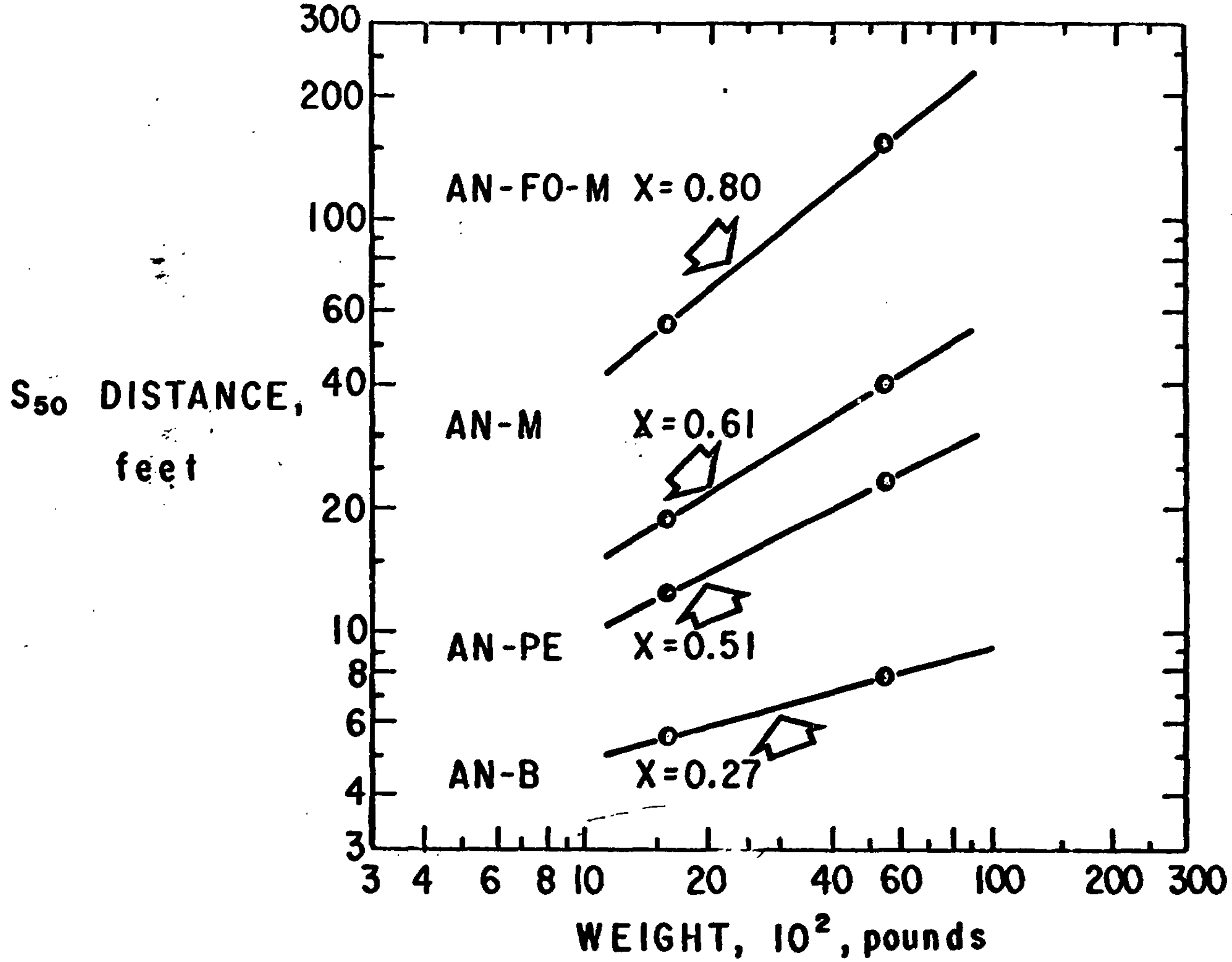


Figure 2

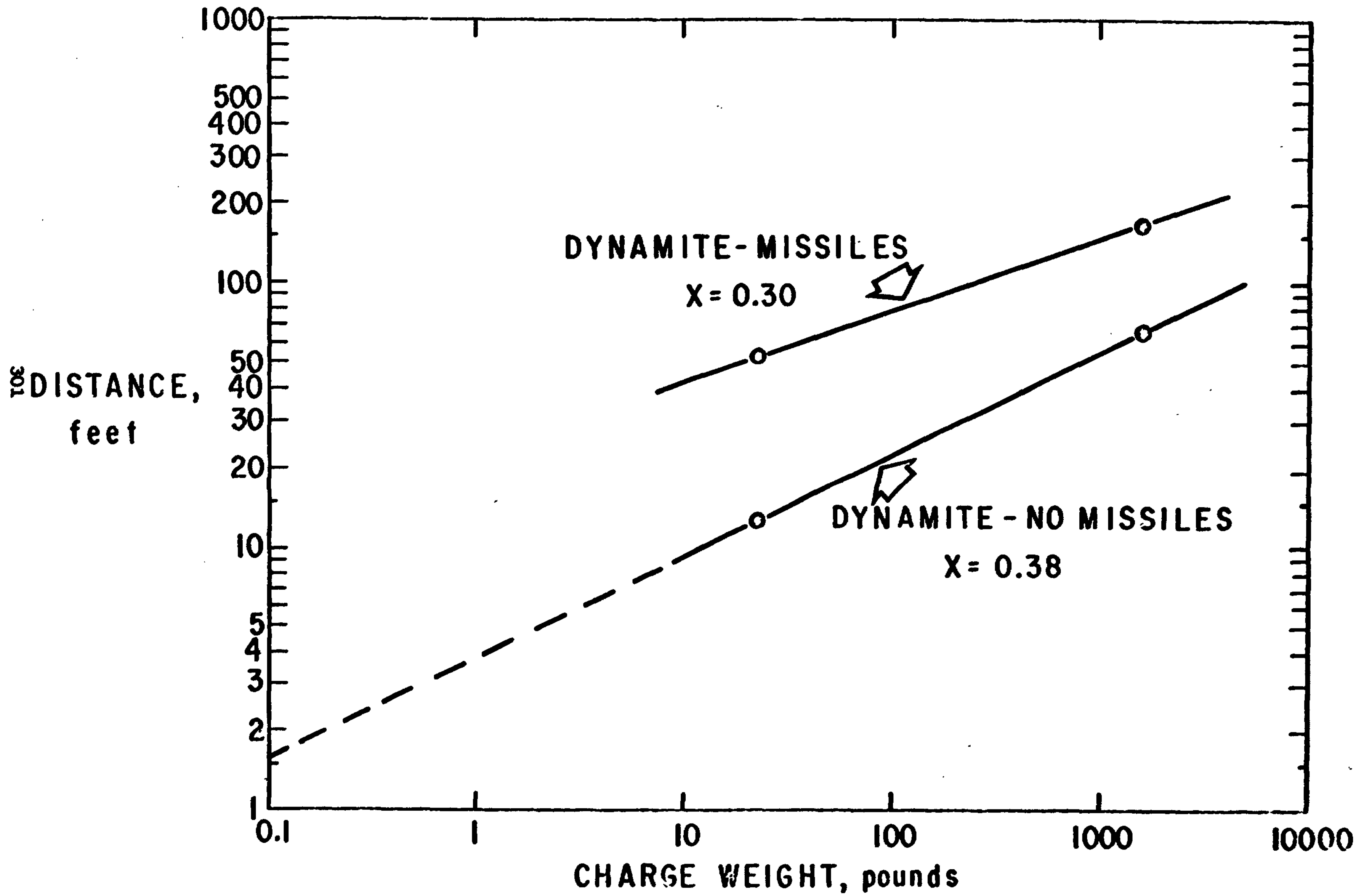

DISTANCE, feet
1000
500
400
300
200
100
50
40
30
20
10
5
4
3
2
1
0.1
1
10
100
1000
10000
CHARGE WEIGHT, pounds
DYNAMITE-MISSILES
X = 0.30
DYNAMITE - NO MISSILES
X = 0.38

Figure 3

PLOT OF AMERICAN TABLE OF DISTANCES SHOWING THREE VALUES OF THE EXPONENT IN THE EQUATION $S = F(W^X)$

From US BUREAU of MINES Report of INVESTIGATION 6903 by R.W. Van Dolah, F.C. Gibson, and J.N. Murphy.

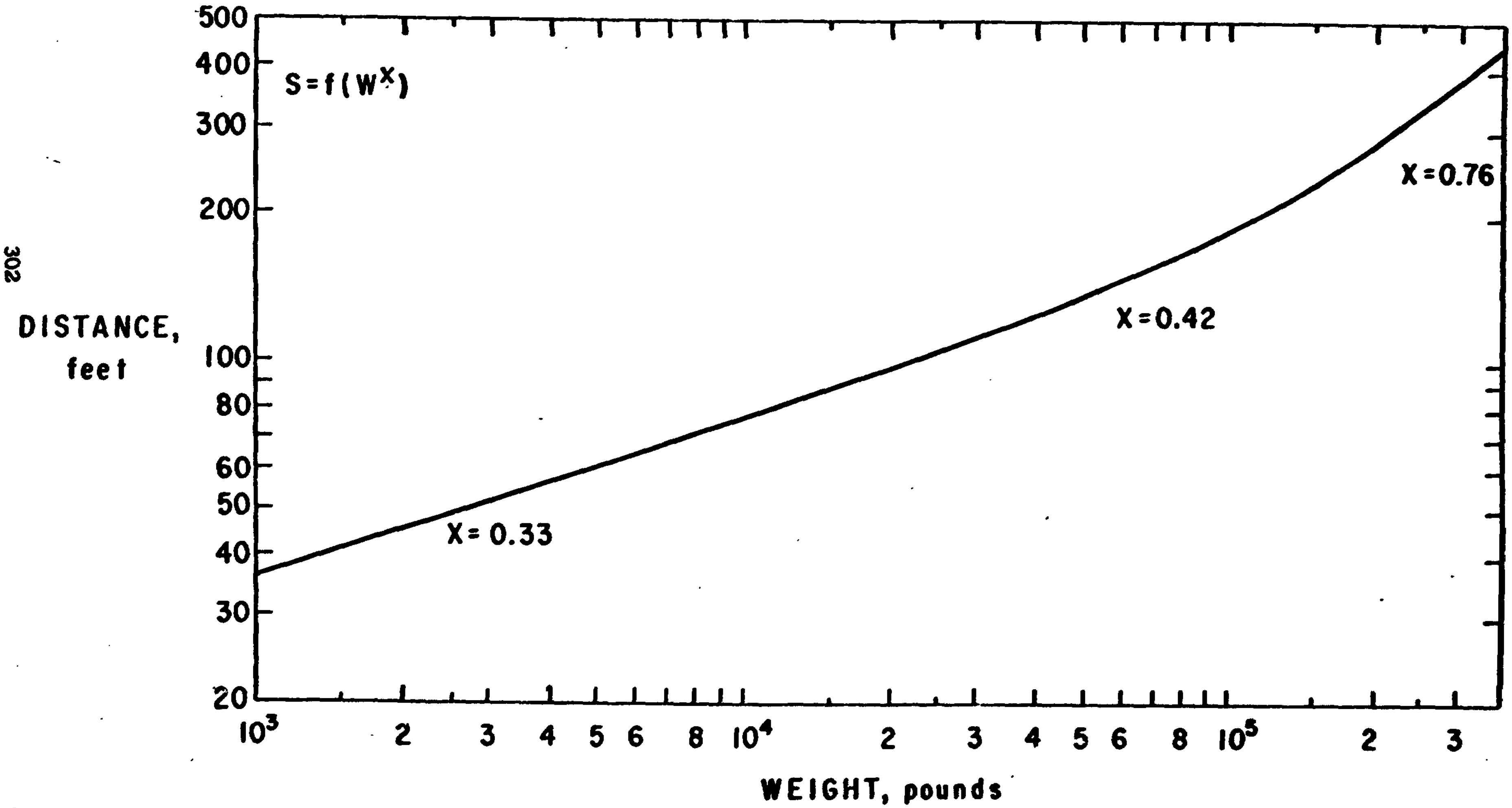
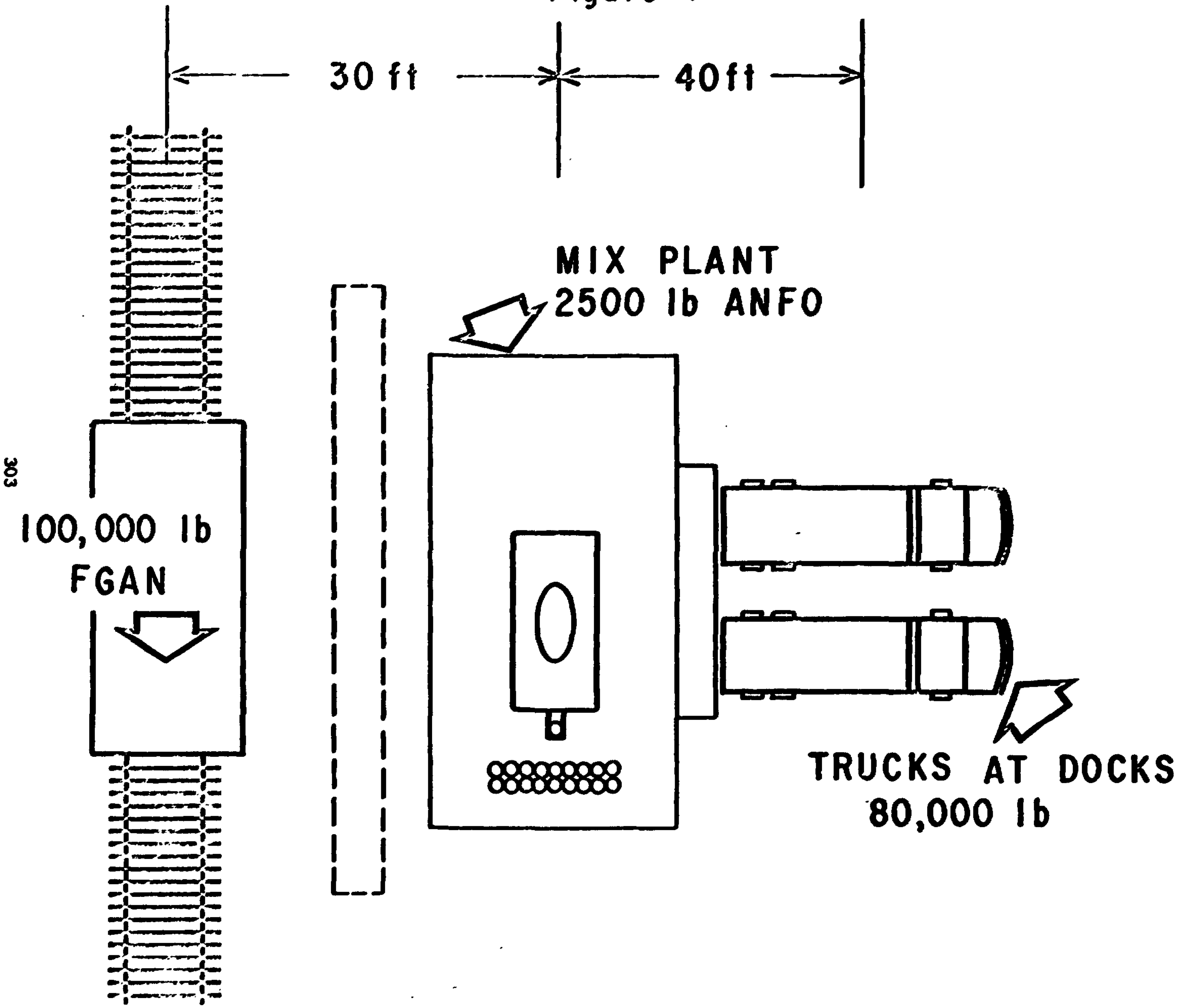


Figure 4



30 ft
40 ft
MIX PLANT
2500 lb ANFO
100,000 lb
FGAN
TRUCKS AT DOCKS
80,000 lb

DR. C. B. DALE, NOS INDIAN HEAD, MD.: I noted on that last slide where you had the trucks placed next to the mixer building that you were measuring from the middle of the trucks to the middle of the mixer building, rather than from the edge of these various components. Can you explain that?

LOVING: Yes, this is one of the areas where I think our committee may have gotten in a little trouble. I mention this in passing. In order to deal with the situation of how to treat combined masses as a donor, we chose to use a center of mass calculation in our examples so that both the individual and combined masses could be independently checked as donors. In this case where the very large mass is farther away, it is obviously unfair to charge the mixer with the total mass. On the other hand, there are situations, particularly in elongated storage like these trucks, where the center of mass does not appear to be the right answer either. And again, in application of the tables, this is the subject that the committee itself will propose a change. We chose initially the center of mass and we checked to be sure we weren't in trouble but I think we are. Not in trouble in the sense that we are prescribing distances too close, but in trouble because our examples don't fit all the combinations that are possible.

L. W. PHILLIPS, NORTH AMERICAN AVIATION: Regarding the test, what actually was considered to be the cause of detonation of the acceptor charge? Was it the flying particles, was it that these particles were hot from the donor detonation, or exactly what did cause the detonation of the acceptor charge?

VAN DOLAH: We agree completely with the first paper this morning that initiation is by fragment and the air blast at these distances is far too weak to effect initiation of these materials. The particles are very hot but they are also traveling at a sufficient velocity that their impact pressure would cause the initiation if they were cold.

PHILLIPS: The reason I ask this question is, having had some experience with ammonium nitrate loading drill holes, blasting drill holes, the method to load the hole was to, under about 40 or 50 psi, impact the drills into the hole in order to get compaction for detonation breakage of the rock and I just wondered what actually caused this detonation in the test?

VAN DOLAH: In that operation, you were dealing, at most, with impact pressures of 100 lbs. per square inch. Here we're dealing with literally tens of kilobars impact pressures which are up in the 100,000 pounds per square inch pressures. Its quite a different situation.

TITAN II LAUNCH FACILITY ACCIDENT BRIEFING
LITTLE ROCK AFB, ARKANSAS

by
Col. Charles F. Strang, USAF
Directorate of Aerospace Safety
Norton AFB, Calif.

The Air Force is vitally interested in conserving Air Force resources and preventing accidents or mishaps.

In spite of our safety efforts, accidents have occurred requiring detailed accident investigations. These investigations are conducted to determine the cause factors and corrective actions necessary to preclude future accidents of a similar nature.

One aspect of fire and accident prevention is to disseminate the lessons learned to groups such as assembled here today. The cause and methods of preventing the recurrence of accidents similar to the Titan II launch facility fire at Little Rock AFB, 1965, are of interest to you.

During my briefing, I will show how, in fire prevention, it is important to properly identify the hazards involved in the use of materials and the need to recognize inherently hazardous tasks. I say this because the hydraulic fluid involved in the Titan II accident is not rated as a flammable fluid by the National Fire Protection Association definitions. However, under certain conditions, it is flammable. Next, I will show how the degree of hazards for welding in an enclosed space is increased by the presence of hazardous materials. Third, I will show why a hazard analysis, application of adequate safety standards, and work scheduling procedures are necessary.

The Titan II launch facility fire at Little Rock AFB occurred while the missile complex was undergoing a modification entitled "Yard Fence," and took the lives of 53 workmen.

Figure 1 is a cutaway schematic of the operational Titan II underground complex. The center portion of the silo, known as the launch duct, contains the missile.

The equipment area is outside the launch duct. There are nine levels within the silo containing many, varied pieces of equipment. The entrance into the cableway is located at level 2. The silo elevator with a 6-person capacity is located next to this entrance.

The cableway at level 2 provides passage to the access portal area, and on to the launch control center.

Normal access to and from the surface is up the stairs in the access portal area.

One of the purposes of the Yard Fence modification program was to increase silo hardening; that is, ability of the entire underground installation to withstand the effects of a nearby nuclear detonation through a "find and fix" program.

This program varied from site to site and included the addition of structural steel reinforcements at various points of the hardness structure to be accomplished by welding.

Other modifications in the Yard Fence program included improvement and repair of the hydraulic and electrical systems, and modification of acoustical liners on the inside of the launch duct.

Yard Fence was initiated in November of 1964, and the contract was let in January 1965.

At the McConnell complexes, work was started in March and completed in June 1965. Work was initiated at Little Rock in June. As of the date of the accident, work on two complexes was completed and two were undergoing modification. Work on the site of the accident had commenced on 16 July. The R/V was removed. However, the missile and its fuel and oxidizer remained in the silo.

I would like to briefly set the stage for the accident.

The lunch hour was from 1200 to 1230 hours. At 1230, the workmen returned from above ground, and, presumably, by 1245 were all back at work. Information derived from work schedules and body positions indicated distribution of the men, by level (see Figure 2) as follows:

Level 1 - 1
2 - 12
3 - 24
4 - 8
5 - 1
6 - 4
7 - 4
8 - 0
9 - 0
1 in elevator - 5 - 6

The 4-man Air Force crew and five maintenance personnel were in the launch control center (see Figure 3).

Mr. A. A. Laborer and one of the survivors testified that shortly after 1300 hours he left the access portal area and went through the cableway to level 2 of the silo in search of a mop and bucket. He went

around the launch duct (shown in Figure 4) and approached a group of men standing around the top of the emergency escape ladder that extended vertically down to level 7. This ladder was used when the elevator was not operating.

While he was standing here and facing outward at the one o'clock position, he stated that he heard a puff of wind. He turned around to his right, and looking in the direction of the water chillers he stated he saw yellow-colored flames reaching to the ceiling. They quickly subsided to a height of about 4'.

The men who were congregated around the emergency ladder made a rush for the ladder. Mr. A realized he would not be able to escape in this direction and decided to reach the cableway by going around the launch duct through the area of the fire. You will note he could not have gone around the launch duct in the other direction -- as the collimator room walls block passage. As he started, the lights went out. He made his way in the darkness, through fire and smoke, to the cableway and then on into the launch control center. He suffered numerous, but not severe, burns of the hands and face.

The other of the two survivors of the 55 people in the silo was working on level 1. He stated he heard or saw nothing. After the lights went out, he smelled smoke. He made his way down the ladder to level 2 and out the cableway. He wasn't overly excited - as testimony to this, he arrived at the LCC with both paint brush and bucket in his hand. He suffered from smoke inhalation, but no other injuries.

At approximately 1308 hours, the missile combat crew commander (MCCC) saw the "fire in Diesel engine area" indicator on his console illuminate. The Diesel engine is on level 3. The MCCC sounded the klaxon horn and made three announcements on the voice signaling system ordering evacuation of the silo.

Shortly afterward, several attempts were made by crew members to penetrate the silo. Initial attempts were turned back by the heavy smoke in the cableway and silo, and heat in quadrant III of level 2. It was stated that even with a flashlight, visibility was no more than than a couple of feet.

I will not describe rescue operations in any detail except to point out that the investigation revealed most of the people on the four upper levels were probably dead within 5 minutes. Those on lower levels may have lived a few minutes more. The missile itself sustained no visible damage.

I will show how we can conclude that the accident was caused by a welder striking a temporarily installed high-pressure, steel-braided hose containing flammable hydraulic oil, causing the hose to rupture and result in a severe flash fire of relatively short duration.

These facts lead to this conclusion. A rupture in a flexible hose was discovered near the floor of level 2. This hose was used in the contractor's temporarily installed flushing rig to flush and clean the HS-2 hydraulic system. (This system operates the silo blast valves and the movable work platforms in the launch duct.)

Figure 5 is a picture of the ruptured hose before removal for further examination. You are looking toward the outer silo wall from the launch duct in quadrant III, level 2.

Figure 6 shows the ruptured hose after removal. You will note that the rupture occurred approximately 4" from the attachment. Independent examination of the hose by two metallurgical experts, Mr. Berman of the Aerospace Safety Staff and the Materials Laboratory at Wright-Patterson AFB, confirmed this rupture to be caused by application of temperatures in excess of 2500°F., such as that created by an electric arc welding rod. Furthermore, the experts state it could not have been caused by an oxy-acetylene torch because there was no charring or burning of the teflon fibers.

Figure 7 is a close-up of the rupture. The break in the steel braids is approximately 1 1/8" long. The hose was carrying hydraulic oil under 500 psi.

Figure 8 is a further magnification of the rupture. Note the fused strands of a single braid of the steel covering. The manufacturer of the hose, Tite Flex Corp., has stated that the teflon inner tube is sold by them as a low-pressure hose and rated at 5 psi.

With the steel braid, they rate the hose at over 1000 psi. With a break in the steel braid as shown, they believe 500 psi would rupture the teflon lining instantaneously.

Examination of the floors of levels 2 and 3 showed large quantities of hydraulic oil spread around, particularly in quadrant 3 and 4 on both levels. Samples of this oil were laboratory tested and shown to be the same as that in use in the rig. Furthermore, measurements of oil remaining in the rig showed that approximately 90 gallons were missing.

Figure 9 shows an elevation cutaway of the temporarily installed flushing rig for flushing and cleaning the hydraulic system. The motor and pump were located at the top. A 1½" iron pipe extended to just above the floor of level 2. The flexible hose was connected at the floor level where the rupture occurred.

Our investigation then considered the possibility of welding being accomplished in the vicinity of the rupture.

There was concrete evidence that welding was being done in this vicinity -- in fact, within 14" of the rupture.

You will note in this slide that a welding machine is at ground level. An electrical line extends through the hole down to level 3. It is looped back up to level 2.

Figure 10 is a picture of the stinger with welding rod as it was found, to which this line was connected. You will note the ruptured hose in the background.

Figure 11 is a cutaway of quadrant III looking from the outside in. The pressure line is here. At these two points, triangular plates were being welded to strengthen the support of a can protecting a spring. This weld had been completed. This weld was one-third completed. An expert welder examined the incompleted weld and stated that in his opinion, it was a very recent weld which had, of course, been subjected to ambient temperatures of around 1000° - 1200° F.

Our postulation is that the welder first tried to make this weld from below (see Figure 12). An expert welder tried this and stated that although he could work from that position, it was very difficult. We postulate that the welder gave up and proceeded to level 2 to try it through the opening in the floor near the silo wall.

Figure 13 is a picture of an investigator kneeling in the place where the welder would have been on level 2. We are looking outward from the launch duct. The investigator's left shoulder is next to the silo wall.

Figure 14 is a picture taken from a position next to the silo wall looking along the wall. The investigator has his hands in position to weld the plate in question. You will note how close the rod would have come to the rupture in the hose. The hose has been removed and the connection covered with a plastic bag.

Figure 15 shows the triangular plate and the unfinished weld more clearly.

Examination of the fire pattern showed the fire centered around quadrant III of levels 2 and 3 (see Figure 16). The motor control center, MCC-1, in quadrant III at level 3, was severely burned. The MCC-1 receives, transforms, rectifies, and distributes all power in the silo. It is located directly under the rupture. The fact that power was disrupted throughout the silo within a minute or less of the initial flash indicates it was badly burned very quickly. Detailed examination of the MCC-1 showed that all identifiable short circuits were a result and not the cause of the fire.

The fire pattern was in complete agreement with our theory. A welder was scheduled to work on this hardness fix from level 3. His body was discovered on level 2 between the ruptured hose and the cableway -- at this point. He could not have reached this position after the accident if he had been on level 3.

This particular welder was the most badly burned of the victims. An autopsy showed that he had suffered flame inhalation. A welding mask and helmet identified as his and found between his body and the rupture, were saturated with hydraulic oil, as were his body and clothes.

Figure 17 shows a recapitulation of the evidence.

So you can see that the fire resulted from a rupture in a high-pressure, flexible, steel-braided hose containing flammable hydraulic oil, which was accidentally struck by a welding rod. The solution to prevention is simple: do not permit welding operations in the vicinity of pressurized lines carrying flammable materials.

Hydraulic Hose Test at Edwards AFB

Arrangements were made by the Air Force for hydraulic hose rupture and fire tests to be conducted at Edwards AFB. The purpose of this test was to validate cause factors of the accident. The overall objective of the test was to demonstrate failure of the hydraulic flushing hose and subsequent hydraulic fluid ignition under conditions and environment known to exist at the time of the accident. Specifically, our test objectives were to determine the:

a. Time and touch of welding arc contact in achieving a similar rupture to the failed hose.

b. Times between welding arc contact and hose rupture; and between hose rupture and ignition.

c. Oil spray pattern achieved from a hose rupture.

d. Ignition and . perature characteristics of hydraulic oil. (MIL-H-6083)

The hydraulic flushing unit actually in use at the launch complex during the accident was airlifted to Edwards. Two static tests and 24 dynamic tests were perf d.

Results:

1. For the two static tests, the rupture pressures of the hydraulic hose were 375 - 381 psig and 275 - 285 psig, respectively. The flushing units operating pressure was 500 psig.

2. There were 16 hose ruptures achieved from the 24 dynamic tests attempted.

3. Subsequently, nine fires resulted from these ruptured hoses.

4. The sources of ignition were determined to be the electrode arc or hot metal droplets produced by the arc.

5. Hydraulic fluid spray burned intensely after ignition and maximum temperature of 2100° F. was obtained.

Test 22

Welder setting	127 amperes
Strands severed	140
Time from beginning of arc to rupture	0.69 seconds
Time from rupture to ignition	0.02 seconds
Total test time	21.8 seconds
Total current time	1.08 seconds
Total hydraulic oil used in 21 seconds	23.6 gallons

Watch for:

Arc
Rupture - Fluid Spray
Fire

(16mm motion picture of Test 22 shown here)

Gentlemen, we feel the yard fence program now exhibits a high state of safety awareness and outstanding enthusiasm.

During recent years, the system safety engineering approach to the implementation of safety has been strongly supported by the Directorate of Aerospace Safety. As a result of developing this system safety concept, as well as from experience gained during accident investigation, safety is now being emphasized throughout the life of the system, from conception until the system is phased out.

The Air Force now requires not only a safety analysis for each new system, but a suitable safety analysis for each existing missile system while undergoing modification.

Each analysis, which is a part of the management plan (see Figure 18) must contain, but is not limited to:

a. A breakout of the entire job by tasks and the evaluation of each task to determine the hazards involved.

b. Corrective actions necessary to minimize or eliminate any identified hazards.

c. A schedule to preclude hazards which could result from task overlap.

d. Manloading based on egress, the existing hazard, and the minimum number of personnel required to accomplish the task.

e. Special precautions required such as the identification of special protective equipment, the development of management's organization and controls, and special safety training required for a particular job.

Gentlemen, your efforts in explosive safety are closely related to fires such as the one described today. In this particular case, the missile and propellants were not affected; however, had the fire caused the propellant tanks to rupture, an explosion would probably have been inevitable. For this reason explosive equivalencies of fuels, determined by the Explosive Safety Board, are an important criteria in siting missile and space booster launch facilities.

I wish you the best of luck in the continuance of your many explosive safety efforts.

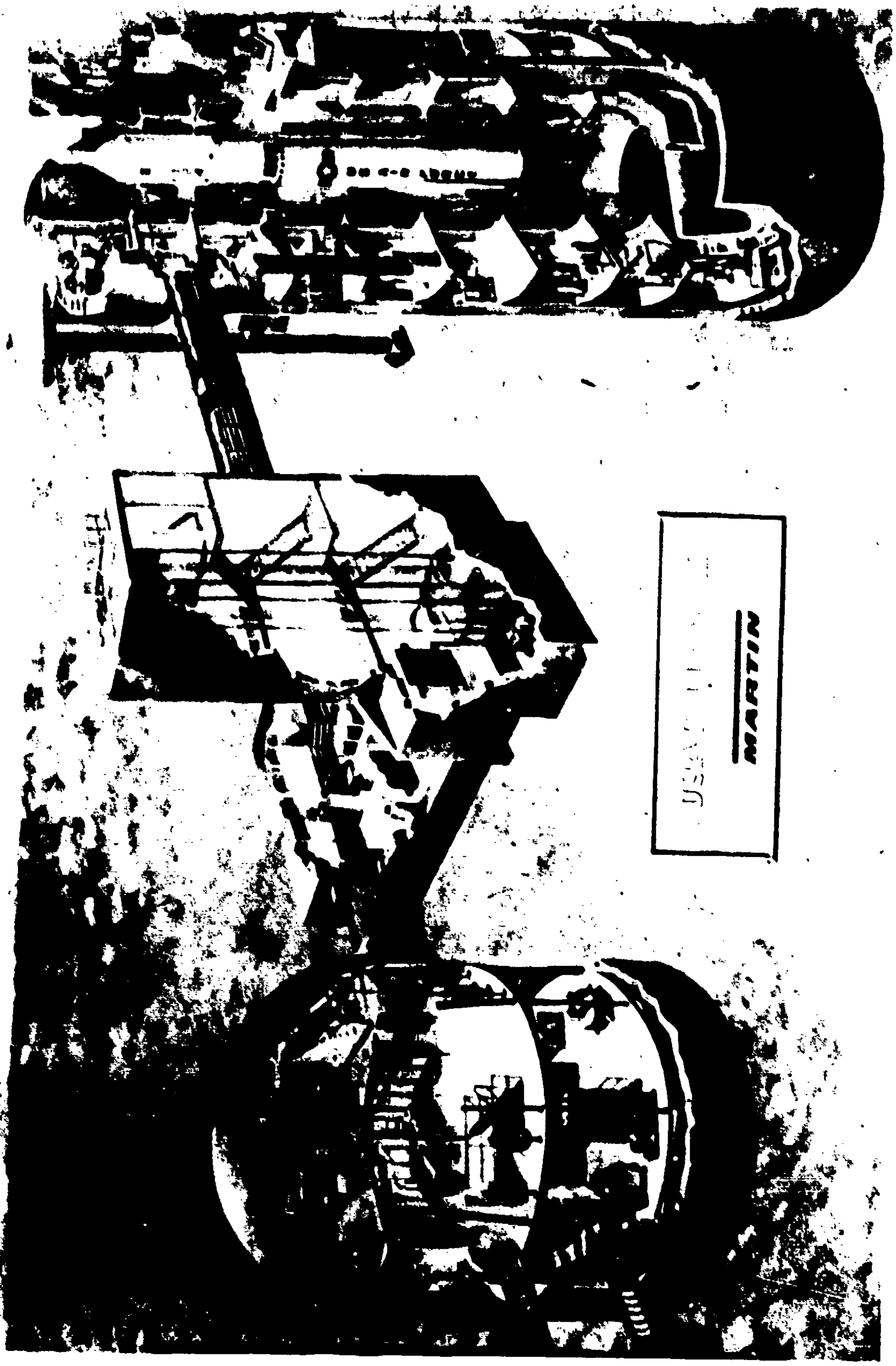


Figure 1

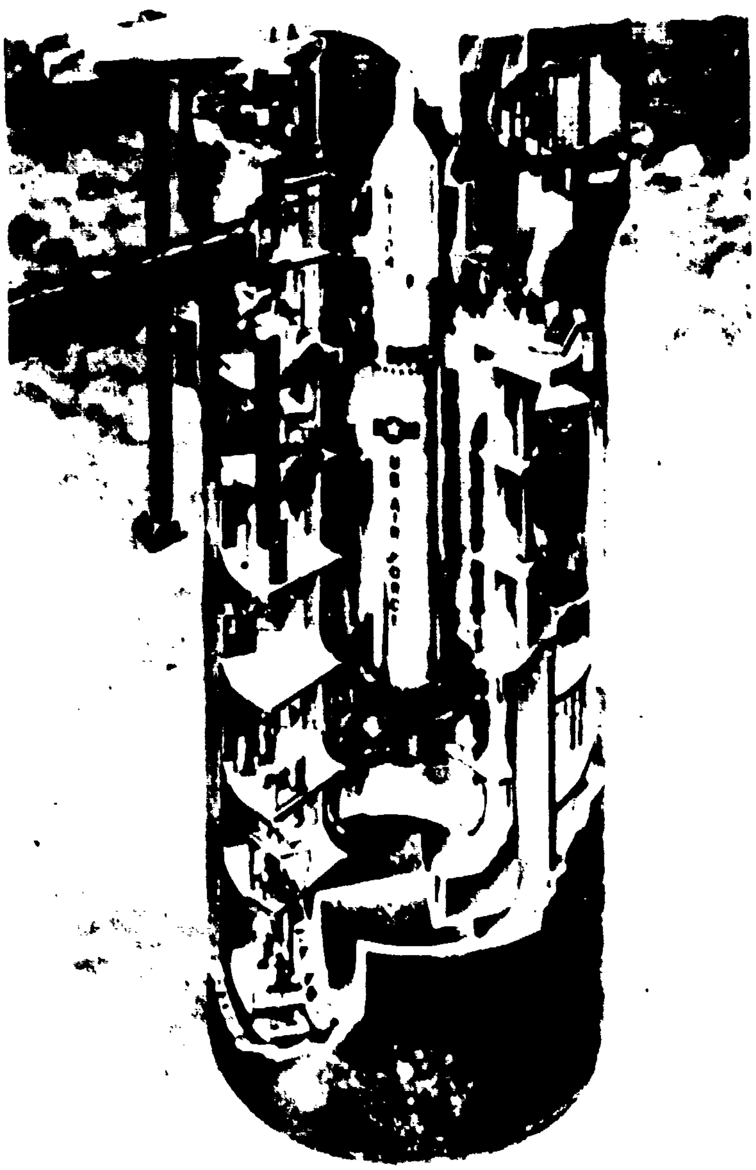


Figure 2

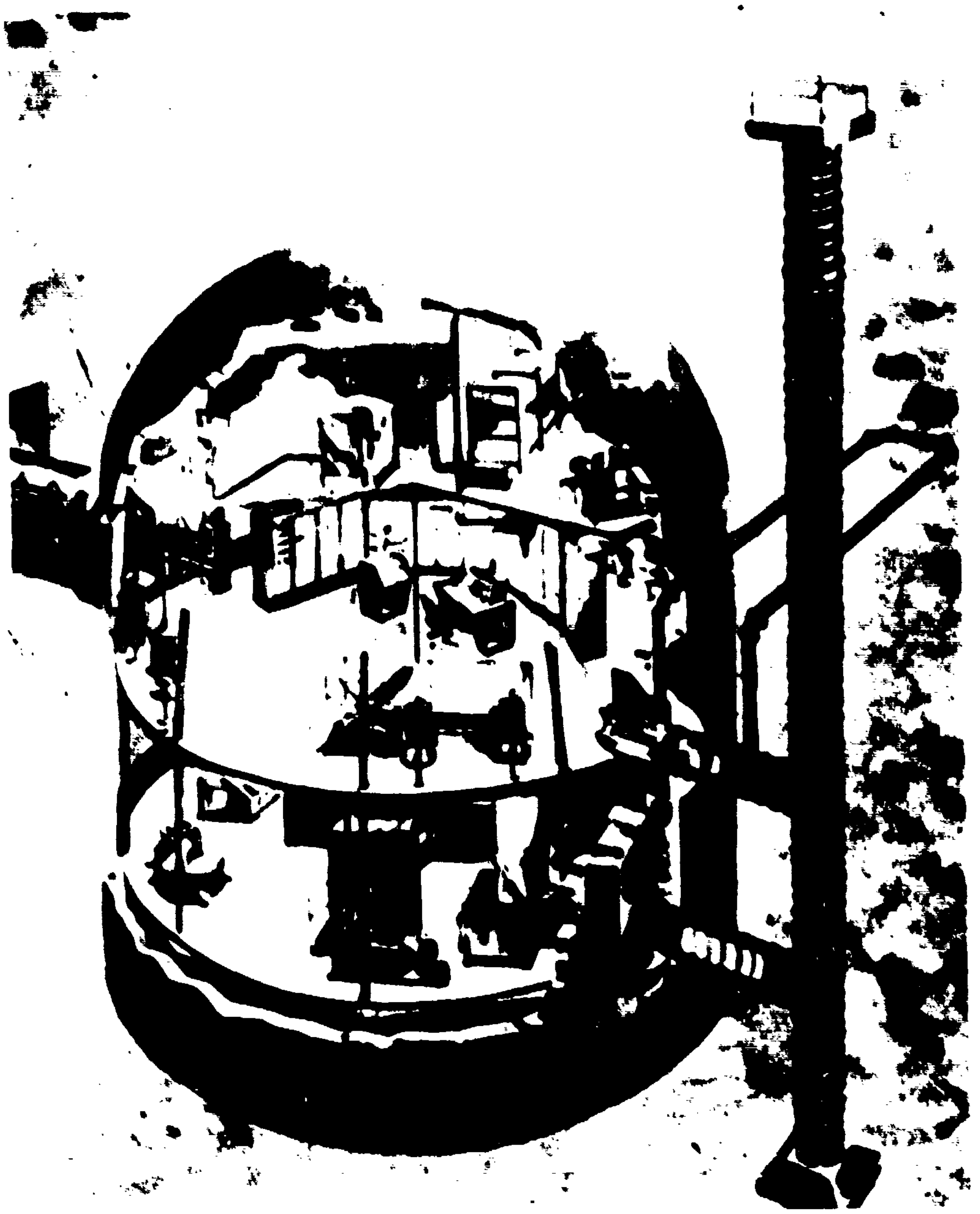
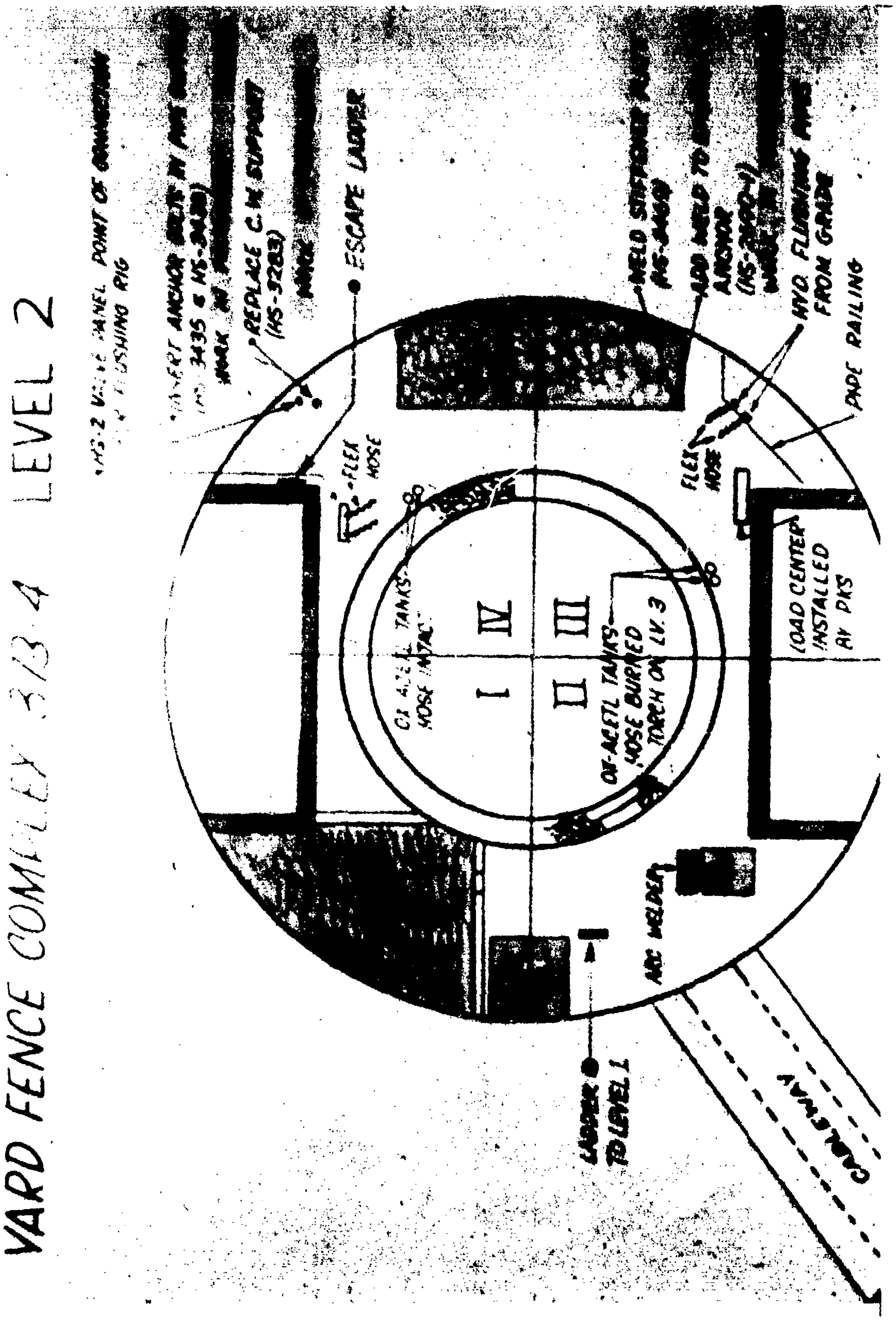


Figure 3



VARD FENCE COMPLEX 3/3-4 LEVEL 2
ESCAPE LADDER
FLEX HOSE
I
II
III
IV
LOAD CENTER INSTALLED BY PKS
PIPE RAILING
HYD. FLUSHING PIPE FROM GRADE
ARC WELDER
LADDER TO LEVEL 1
CABLEWAY

Figure 4

Figure 5

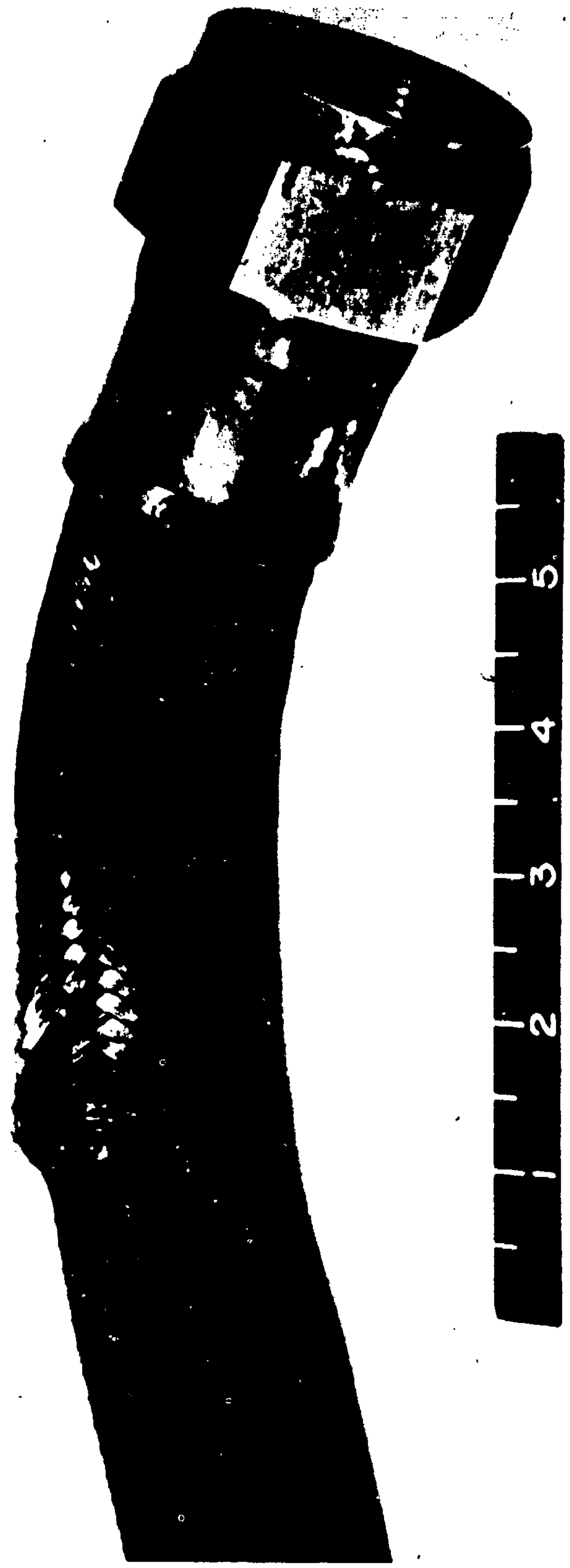


Figure 6

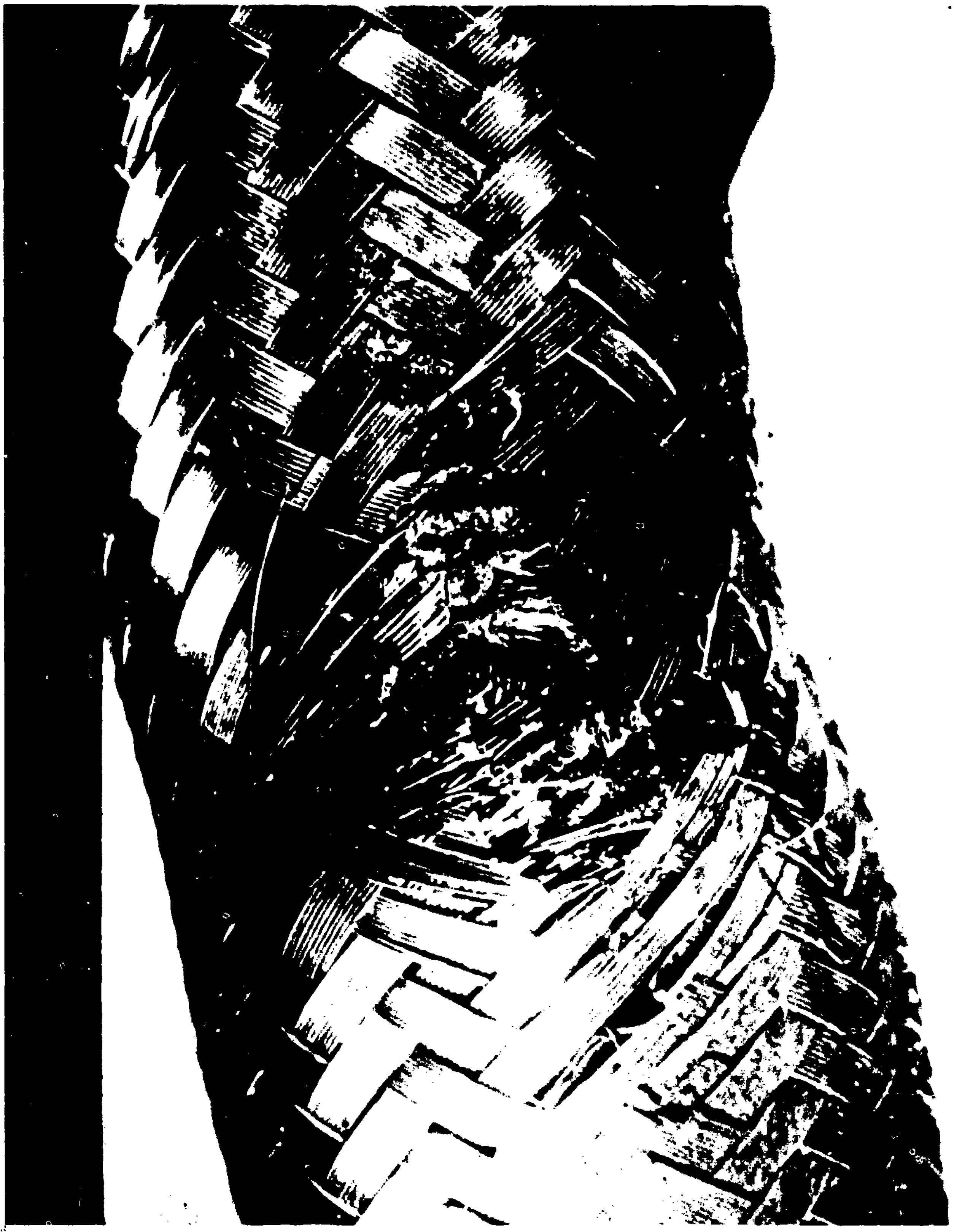


Figure 7

Figure 8

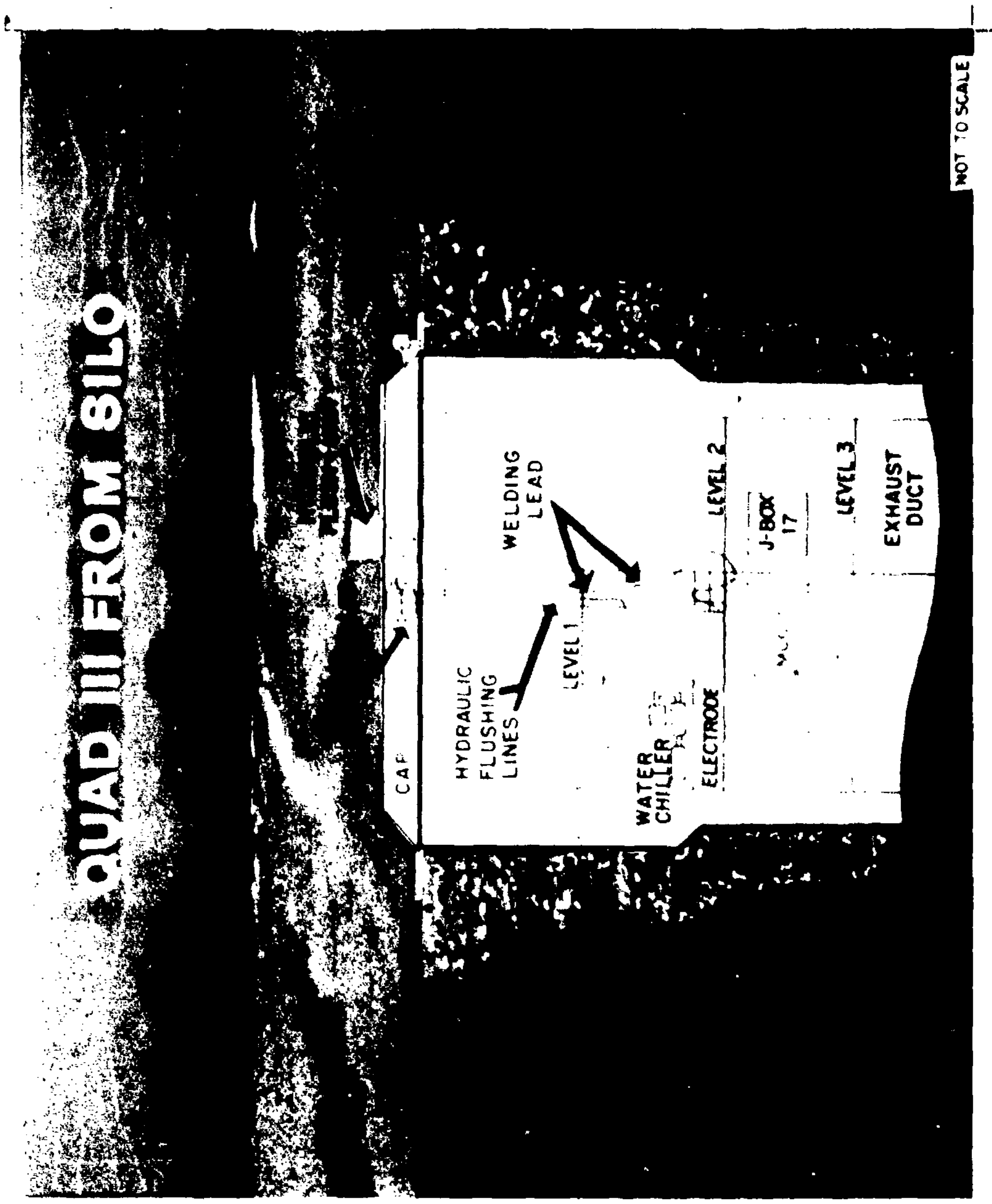

QUAD III FROM SILO
NOT TO SCALE
CAP
HYDRAULIC FLUSHING LINES
WELDING LEAD
LEVEL 1
LEVEL 2
LEVEL 3
WATER CHILLER
ELECTRODE
J-BOX 17
EXHAUST DUCT

Figure 9

Figure 10

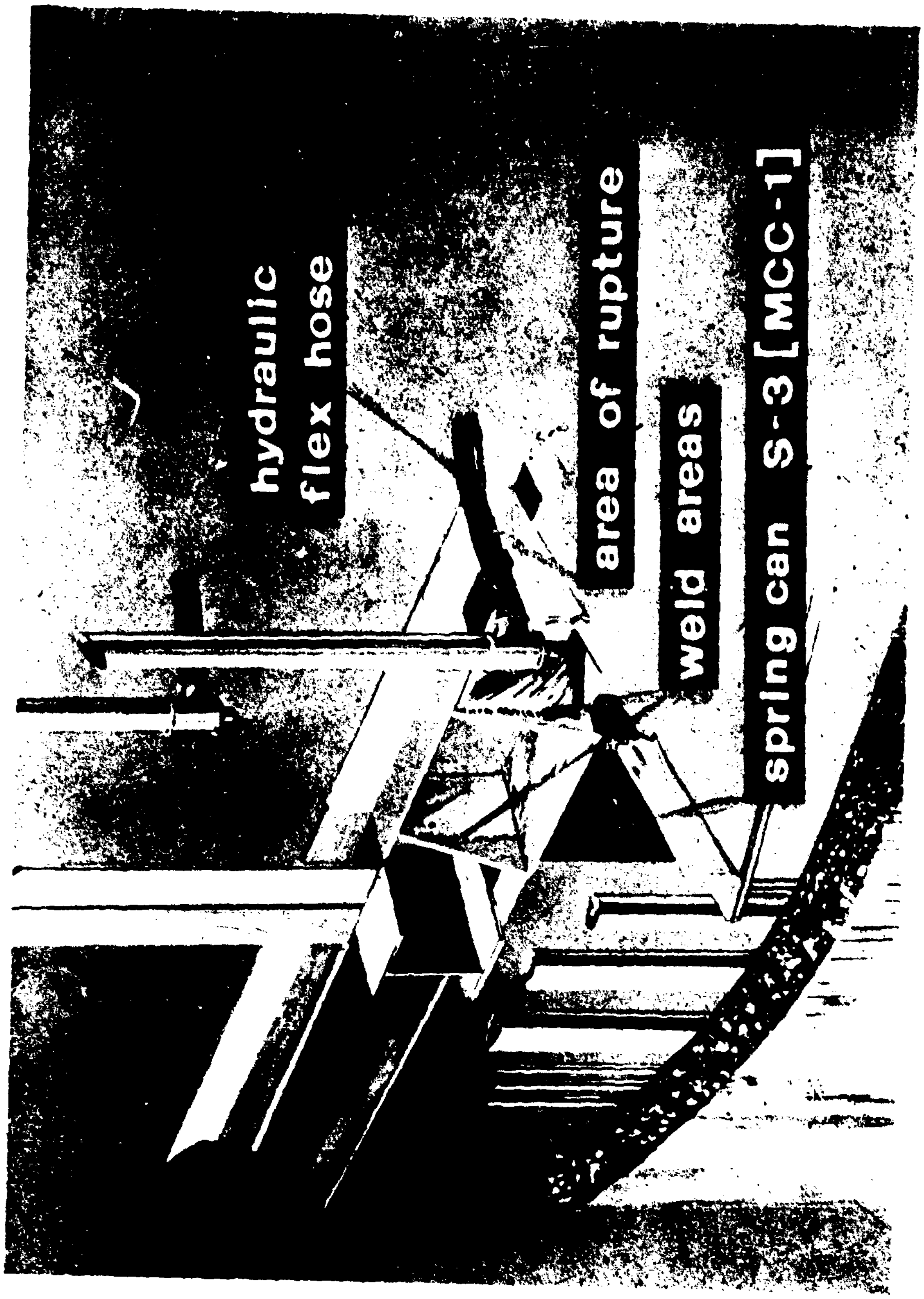

hydraulic
flex hose
area of rupture
weld areas
spring can S-3 [MCC-1]

Figure 11

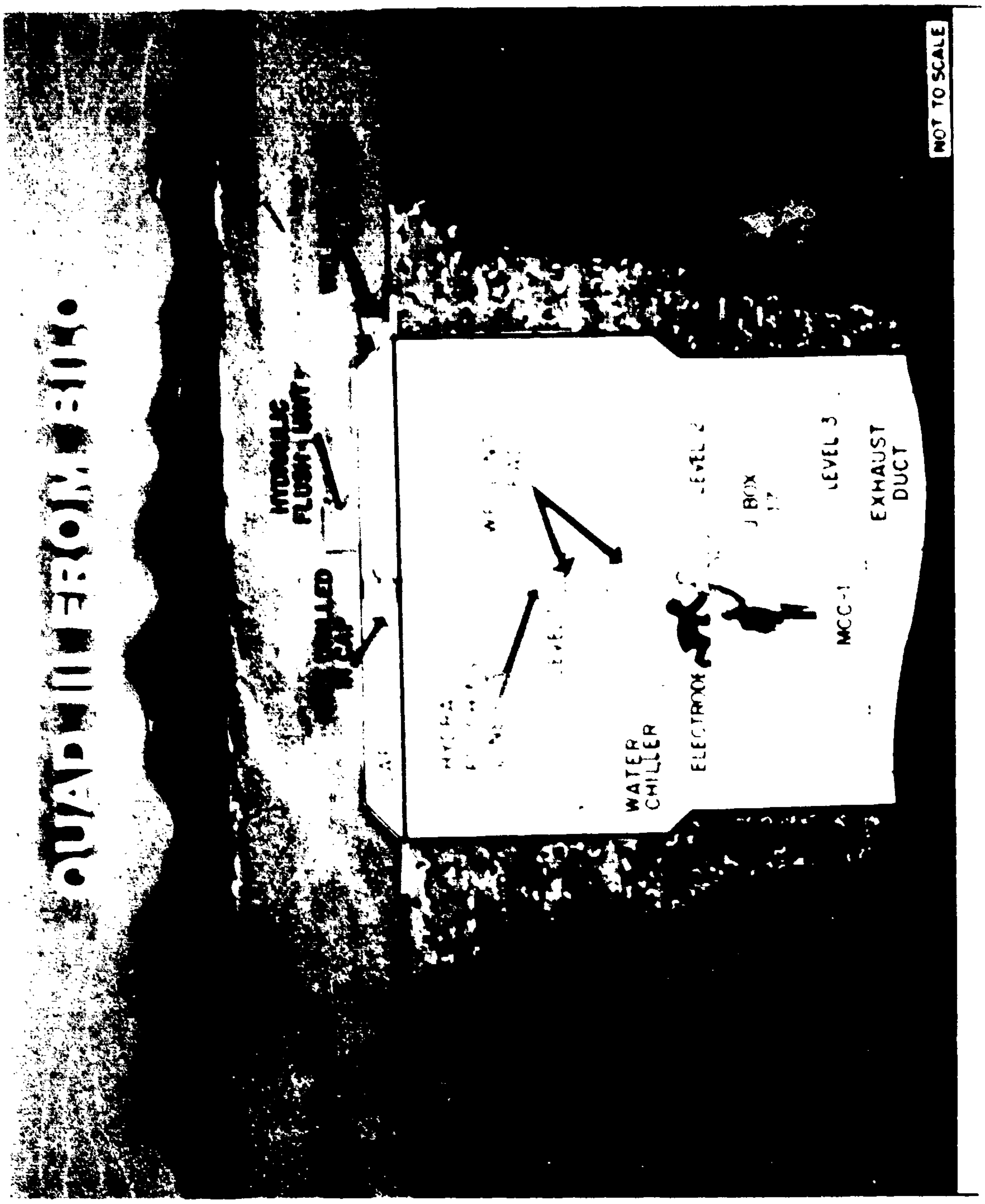

NOT TO SCALE
WATER CHILLER
ELECTRODE
MCC-1
LEVEL 3
EXHAUST DUCT
HYDRAULIC FLUSH UNIT

Figure 12

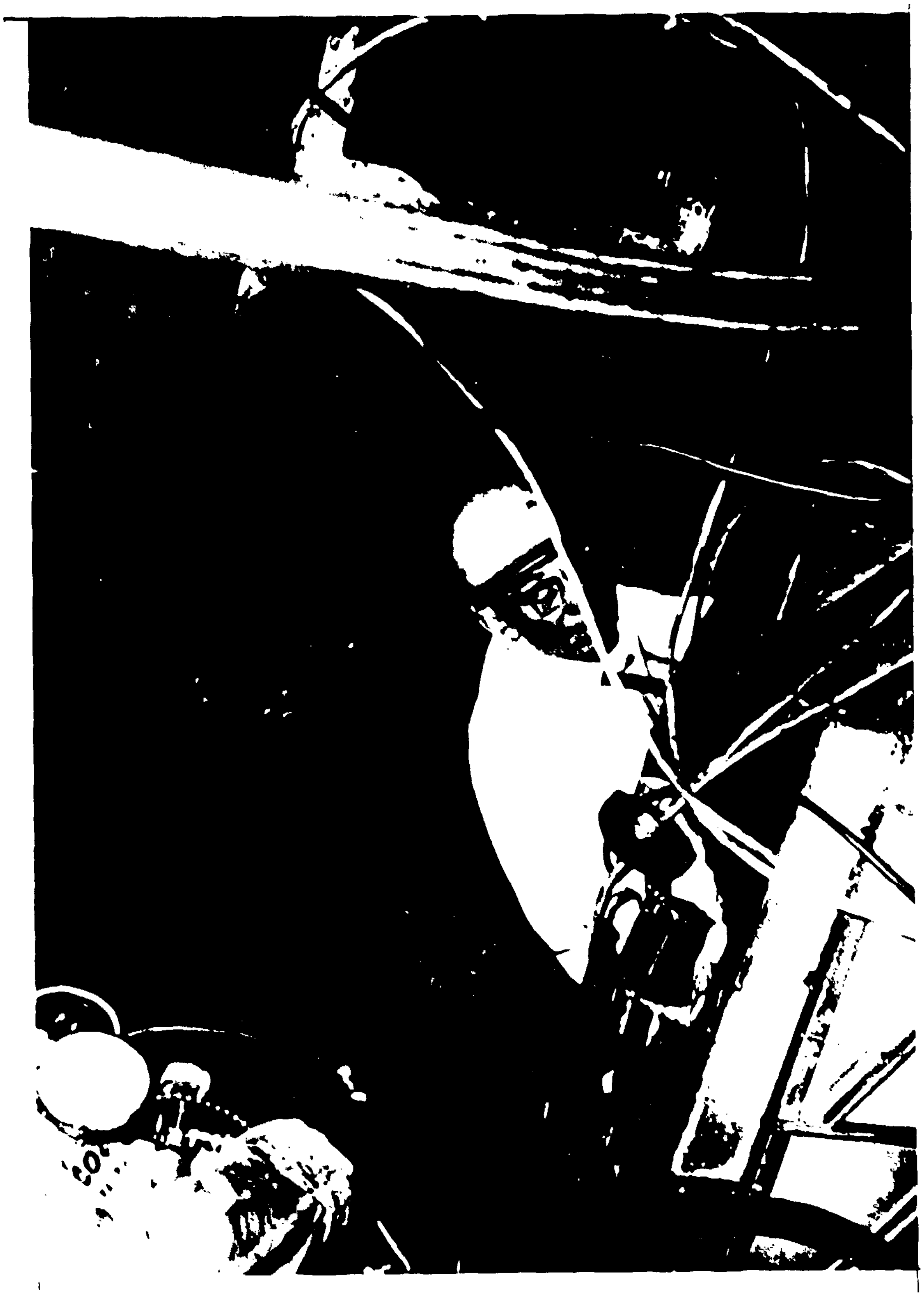


Figure 13

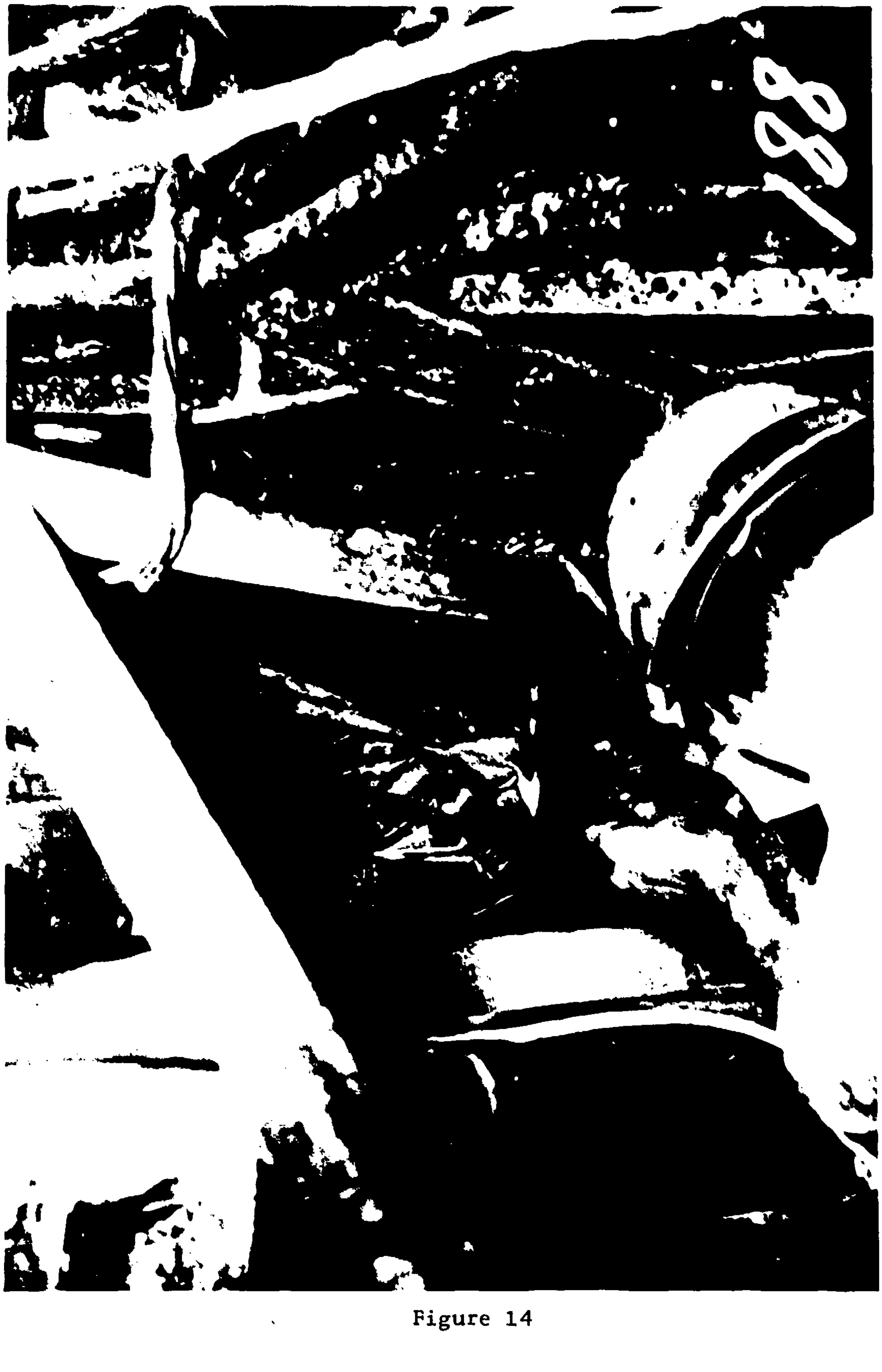


Figure 14

Figure 15

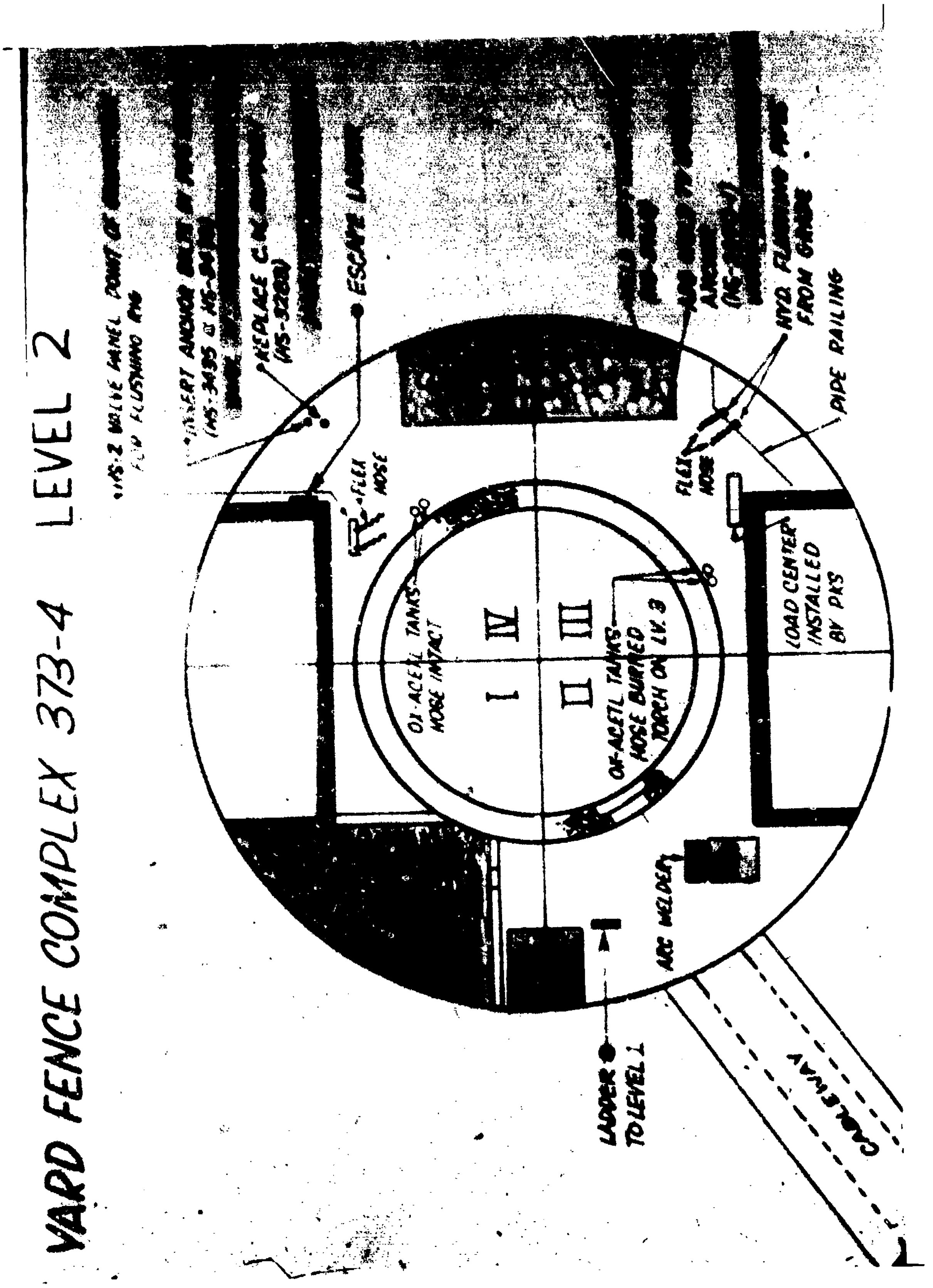

YARD FENCE COMPLEX 373-4 LEVEL 2
ESCAPE LADDER
FLEX HOSE
OX-ACETYL TANKS HOSE INTACT
OX-ACETYL TANKS HOSE BURIED TORCH ON LV. 3
LOAD CENTER INSTALLED BY PKS
HYD. FLUSHING PIPE FROM GRADE
PIPE RAILING
ARC WELDER
LADDER TO LEVEL 1
CABLEWAY
I
II
III
IV

Figure 16

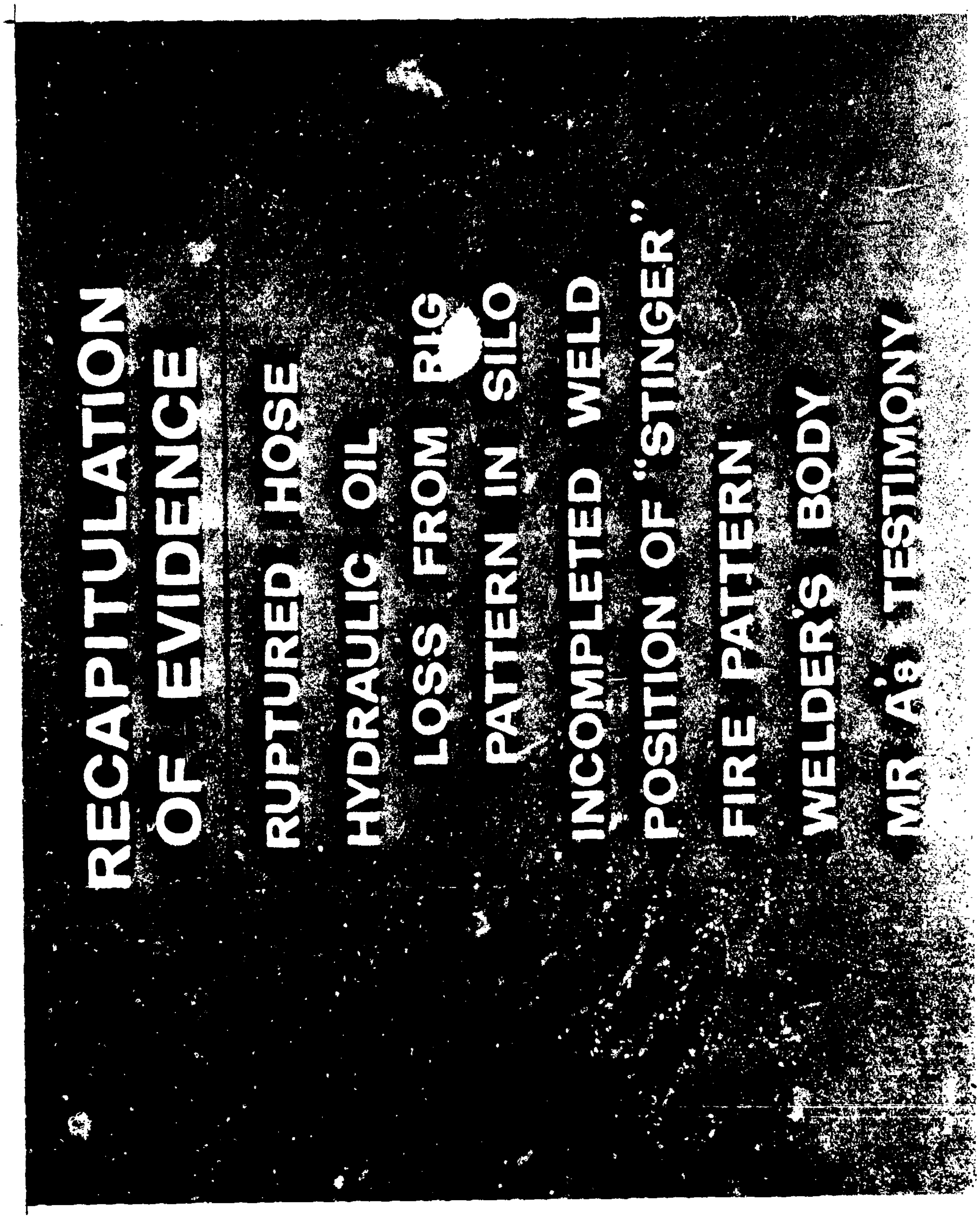

RECAPITULATION
OF EVIDENCE
RUPTURED HOSE
HYDRAULIC OIL
LOSS FROM RIG
PATTERN IN SILO
INCOMPLETED WELD
POSITION OF "STINGER"
FIRE PATTERN
WELDER'S BODY
MR A's TESTIMONY

Figure 17

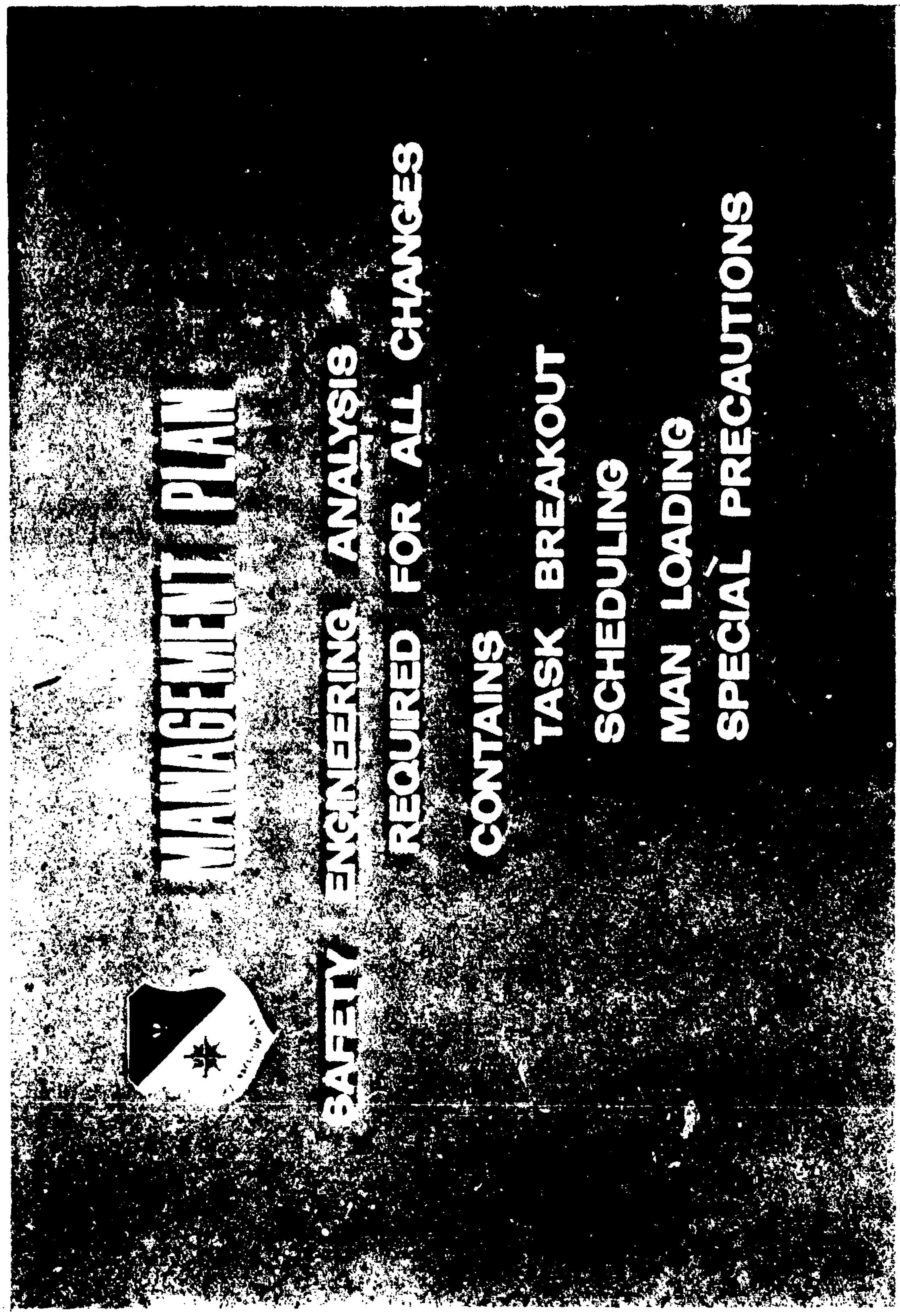

MANAGEMENT PLAN
SAFETY ENGINEERING ANALYSIS
REQUIRED FOR ALL CHANGES
CONTAINS
TASK BREAKOUT
SCHEDULING
MAN LOADING
SPECIAL PRECAUTIONS

Figure 18

B. LEVENS, DOUGLAS AIRCRAFT CO.: Has any consideration been given to using a non-combustible hydraulic fluid such as one of the phosphate esters or similar materials?

STRANG: Yes, so far what we can find is that there is only one, I forget the name of the company that makes it. It's close to being non-combustible, I don't believe its fully non-combustible. We are told and we have the document that shows it runs some $350 a gallon, so its a little out of reach right now.

H. L. TRACY, NORTH AMERICAN AVIATION: I understand that the fire was confined to the second and third level, was that correct?

STRANG: That's right.

TRACY: What was the cause of death of the men at the lower level, was it asphyxiation?

STRANG: Asphyxiation.

L. C. EWING, ATLAS CHEMICAL INDUSTRIES: Could you tell me if there was a flame or a hot work permit system in effect at the time of this accident? Did you have a system where a man had to have a permit written out before he could strike an arc in the area?

STRANG: We have a requirement for a welding permit for each and every job, very closely controlled. In this particular case the welder unfortunately went to the level 3 above him and left behind him a helper. Of course the helper has a fire extinguisher and these type things?

EWING: Who would survey the area and issue this permit and allow them to weld in the area?

STRANG: The contractor, supervised in this particular operation by the Corps of Engineers for the Air Force. The Air Force is still ultimately responsible.

EWING: Would it have been a safety individual or just one of the supervisors of the contractor?

STRANG: It would be the supervisor of the contractor with the safety brought into it, he assigns them.

G. F. HUGHES, NWS YORKTOWN, VA.: Did you investigate the water glycol type of hydraulic fluid?

STRANG: Negative.

HUGHES: They're very cheap.

STRANG: When you said investigate I was thinking of the accident itself. You're talking about a fluid to be used in the Titan itself. Absolutely, yes. But we can't because of its characteristics.

BRIEFINGS ON LATE ACCIDENTS

were presented by:

Mr. Lou Jezek
Army Materiel Command
Washington, D. C.

Mr. J. J. Molloy
Rocketdyne Division
North American Aviation
Canoga Park, Calif.

Mr. E. L. Craig
Naval Weapons Station
Concord, California

ONE-HALF DAY SPECIALIST SESSION

"PROCESSING OF HE AMMUNITION, PYROTECHNICS, AND INITIATING SUBSTANCES"

Session Chairman:

Mr. Ray Myers

Director, AMC Field Safety Agency

Charlestown, Ind.

Speakers:

Mr. Chas. R. Goff, Day & Zimmermann, Inc., Texarkana, Texas

Mr. John E. Jamison, Mason & Hanger-Silas Mason Co., Burlington, Iowa

Mr. W. C. McCay, Longhorn AAP, Marshall, Texas

Mr. J. M. Richardson, Sperry-Rand Corp., Shreveport, La.

PROCESSING OF INITIATING EXPLOSIVES

Mr. Charles R. Goff
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Day & Zimmermann, Inc.
Lone Star Army Ammunition Plant
Texarkana, Texas

Mr. Chairman, members of the Armed Services Explosive Safety Board, guests. My talk today is on the subject of initiating explosives used in the loading of small component items, the safety problems involved, what has been done about them, and what still needs to be accomplished.

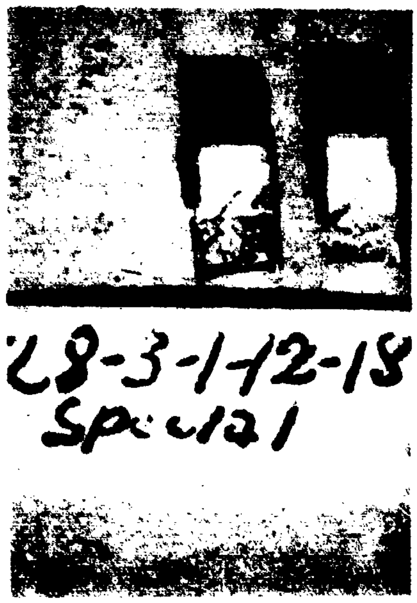
For purposes of simplification, I will confine my discussion primarily to detonator loading. The problems involved can be categorized into three operating steps. First, the preparation of explosives for loading, second, the actual loading and consolidation of the explosives into the detonator and third, the packaging of the completed detonator. From the standpoint of safety, comparatively little has been accomplished in the first phase and much has been accomplished in the last two.

The handling of initiating explosives such as Lead Azide and Primer Mix has been a safety problem in the ammunition loading industry from the time these explosives were first used. The problem is still with us despite great strides in mechanization. Since initiating explosives are required to spark the explosive train, they must, of necessity, be extremely sensitive to spark, friction, impact, crushing, etc. to guarantee functioning of the item in which they are used. Let me show you some examples of what we are talking about.

Slide #1

This slide shows the relationship of small XM Relay that is essentially a detonator on the left and large M50 Detonator on the right to a dime.

As you can see, we are discussing loaded components that are very small. Obviously, the explosive content is very minute, yet must be powerful enough to set off the next step in the explosive train and sensitive enough to function every time.



Slide #2

This slide shows the relationship of initiating explosives consolidated in the M55 Detonator. This detonator is slightly larger than the smaller component in the first slide. At the top are approximately 32 milligrams of LCA Primer Mix, in the middle are approximately 70 milligrams of RD-1333 Lead Azide, and on the bottom are approximately 57 milligrams of HMX.

Slide #3

Although the operator is protected by an operational shield, her hands are exposed in the event of an explosion of the one-ounce receptacle. This hand scooping of initiating explosives was the accepted method until Day & Zimmermann, Inc., Contractor Operator of the Lone Star Army Ammunition Plant, Texarkana, Texas, designed and proved the first automatic loading device known as the Frictionless Loader.

Slide #4

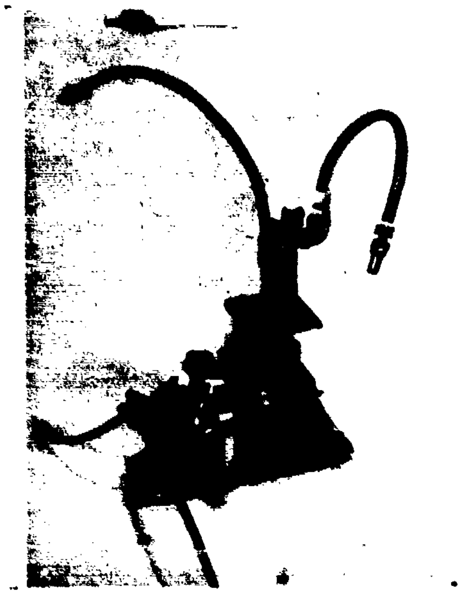
This picture shows the old method of loading detonators by hand and again, even though operational shields are used, hands were exposed.

Slide #5

As soon as the Frictionless Loader was developed and proven, we installed them in regular hand lines. This eliminated the hazardous hand scooping operation. The main incentive to develop an automatic metering device was created by the introduction of RD-1333 Lead Azide into detonator loading, in place of dextrinated Lead Azide.

This was necessary as new fuze design requirements dictated smaller detonators, yet greater output. Dextrinated Lead Azide could not meet the requirement.

RD-1333 Lead Azide was much more sensitive to shock, friction, etc. and could meet design requirements. Unfortunately, it further increased the hazard of hand scooping sensitive materials.



Slide #6

Here is a slide of the Frictionless Loader by itself as previously shown on the hand line operation.

This is the first of three automatic metering devices which has been developed by Day & Zimmermann at Lone Star. After the development of these loaders, they were installed on a Jones Loading Machine.

The Frictionless Loader uses the hour glass principle as the initiating explosive is continually running through the funnel and a movable chute beneath the funnel interrupts the flow thereby resulting in either metering the initiating explosives or returning it to the water-wheel that in turn dumps the powder back into the top of the funnel. This machine is used for both dextrinated and RD-1333 Lead Azide.

Slide #7

The Chamlee Loader was developed as an improvement over the Frictionless Loader and used what we term the flip-flop principle inasmuch as the loading cup is filled in one position and is then rotated 180° and this permits the powder to fall through a funnel into the detonator.

Slide #8

The Cargile Loader was developed specifically for the loading of Primer Mixes. Primer Mixes do not flow as readily as Azides, especially NOL 130 Primer Mix which tends to cling to the scoop or funnel and will not free flow. This loader can also be used for Azides but does not have the accuracy for Azides as the other loaders. The mechanism for this loader re-creates mechanically the movements of a human hand while scooping.

Slide #9

This is a typical Jones Loader. It is automated in movement from one operation to another and for consolidation of explosives. It still required hazardous hand scooping of sensitive initiating explosives. These machines have now had the automatic metering devices added.

In order to eliminate all manual operations, we are at present attempting to develop. as many have tried to develop in the past, an automatic device for packaging detonators as produced by these machines. If we are successful, we will eliminate all manual stations on Jones Machines.

This Jones Loading Machine is relatively versatile but it cannot load small components with more than three increments. A machine had to be designed, therefore, that could be used to load, automatically and remotely, detonators requiring four or more increments. With the development of automatic loading devices behind us which could be used on a new device, we developed a detonator loading machine known as the Trans-o-mator.

6

Slide #10

This machine known as the Trans-o-mator automatically loads the inert metal cups into the stations, performs the necessary initiating explosive loading steps, consolidates, inserts closures, crimps, inspects, separates rejects from acceptable detonators, and ejects finished production into receptacles. In other words, detonators are loaded by this machine completely automatically. This machine does not have the automatic packaging yet, so that phase is still lacking, but as I previously mentioned, we are working on it.

I would like to refer back to my reference to the great sensitivity of RD-1333 Lead Azide.

Not only was the hazard of hand scooping increased by its introduction, detonators loaded with RD-1333 Lead Azide have exploded inside cardboard packages while at rest, in holding barricades, several hours after they had been loaded -- with no outside initiating force being applied. As a result of this, we engineered a new type final pack for detonators that prevents propagation within the package, should one detonator explode.

Although we at Day & Zimmermann have been able to develop an almost completely automated machine for filling detonator cups by the use of a Trans-o-mator, along with automatic metering equipment, and packaging to preclude propagation, this is not the complete story. There is still much to be done to eliminate the final manual operation during the loading process. We need equipment to package detonators

automatically as they leave the Jones Machines or Trans-o-mators. We are now in the early stages of design of equipment for this purpose. We think we are proceeding in the right track.

There still remain the processing problems of washing, drying, screening, blending, etc., of the various Azides and Primer Mixes prior to their introduction to the automatic loading equipment. To avoid manual handling will require many hours of design and engineering to develop equipment and processes. It is true that most of these operations are accomplished behind substantial dividing walls which, in the event of an incident, would successfully contain an explosion and protect personnel. There still remain requirements for manual handling of these sensitive explosives between the various operations. These constitute a hazard that needs solution.

The development of successful automated equipment and procedures for the processing of these explosives prior to automatic loading requires money. So few people are involved in this work that it is not possible to carry out the development of such automated equipment on a self-amortizing basis. It is therefore necessary to make an investment in safety. This should receive a high priority as we go to more and more sensitive initiating explosives.

MUCOM recently appropriated funds to study the characteristics of RD-1333 Azide. An appropriation to finance the development of safer methods for preparation of these explosives for detonator loading would be a step forward. A successful program in this area would go far toward eliminating manual handling of initiating explosives - the ultimate answer to insure the safety of personnel in all aspects of detonator loading.

MELT POUR EQUIPMENT FOR 175MM SHELL AT IOWA AAP

Mr. John E. Jamison
Safety Director, Mason & Hanger-Silas Mason Co., Inc.
Iowa Army Ammunition Plant
Burlington, Iowa

Because of the many serious quality troubles encountered in loading projectiles of 155MM size and larger, there has been a serious need throughout the industry for many years for better equipment and processes. We feel that the equipment we are about to discuss answers that need and improves the overall safety in melt pour operations.

In this discussion we will explain the design and operation capabilities of the new Melt-Pour equipment at Iowa Ordnance Plant.

Although the line is presently tooled for 175MM projectiles, the equipment is designed to accept any caliber shell from 155MM through 240MM, with a minimum retooling cost.

Figure 1 (Plan view of building)

The building in which our equipment is installed is a typical melt building in a typical load line layout. It was originally designed for loading bombs and was used for that purpose late in World War II. Since then it has been used primarily for loading 240MM and 8 inch Projectiles. In February of this year we began loading 175MM Projectiles. As you can see in this partial plan view of the first floor of the building the installation of the five conditioning ovens very nearly occupies what was formerly the cooling bay. There is sufficient space left; however, to install three additional ovens if an increased schedule should make it necessary. On the far left, completely sealed off from pouring operations are the makeup tanks, heat exchangers, pumps, motors and controls used in the hot water circulating systems. The hydraulic units that drive the kettle agitators are also located here. In the middle of the slide the rectangular objects are tank trucks being indexed through the funnel preheat oven into the pouring machine. The two dotted circles indicate the location of the melt kettles on the second floor.

Figure 2

In this slide you see a cross section of our melting and pouring equipment. At the top of the slide are the two kettles which are located on the second floor. Drawoff of Comp B is controlled by a special air actuated plug type valve of Mason & Hanger-Silas Mason Co., design. These valves are designed to fit into the kettle drawoff opening and conform to the inside kettle curvature. The purpose of this design is to preclude settling of RDX at the kettle discharge outlet.

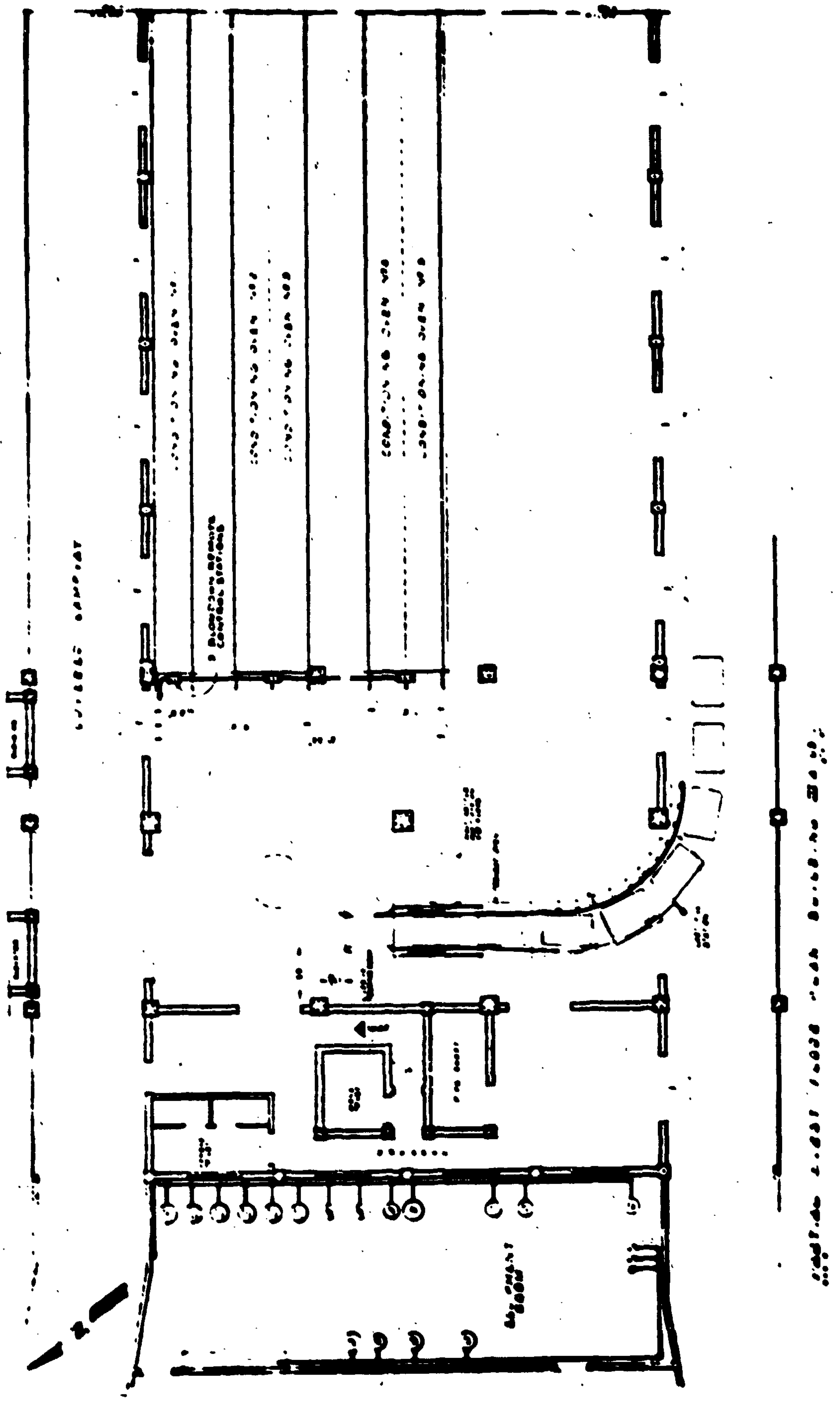


Figure 1

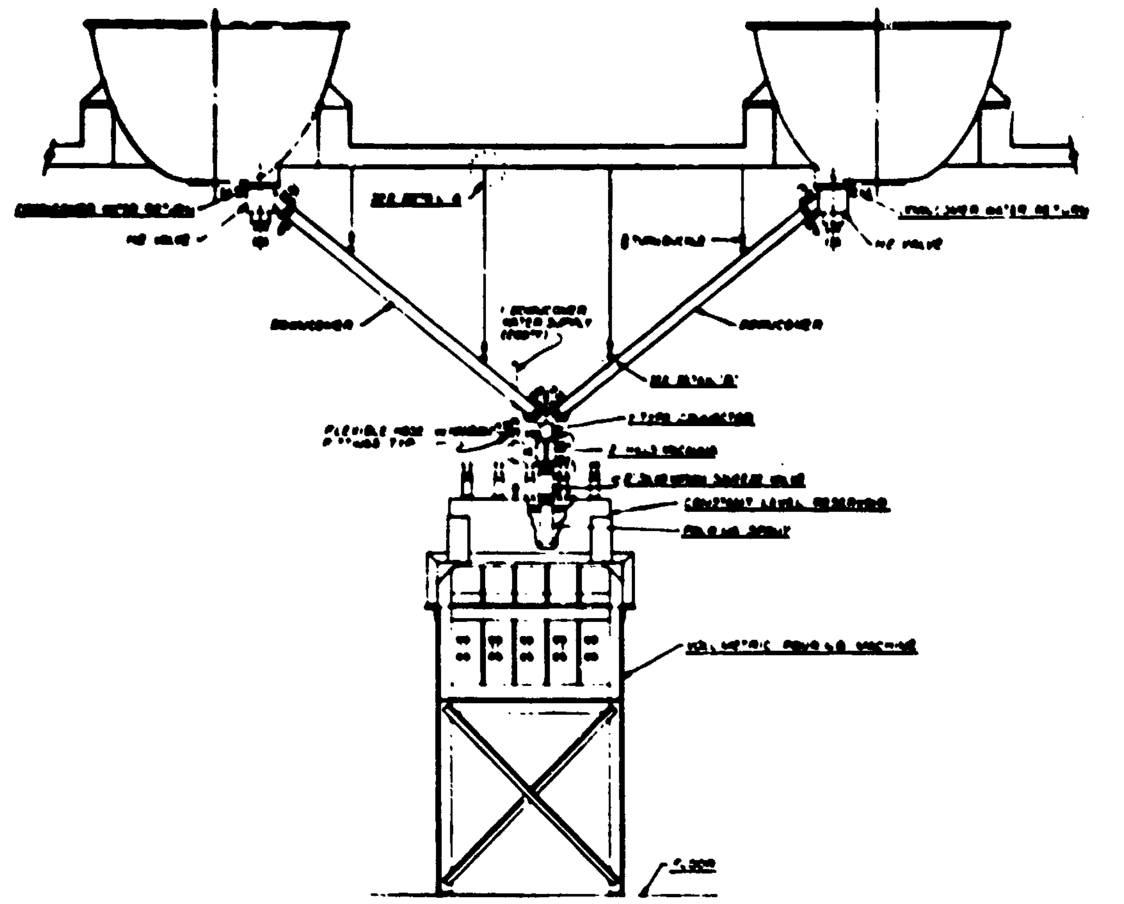


Figure 2

The pitch of the downcomers are approximately thirty degrees to assure adequate flow. Immediately below the "Y" type connector is an air actuated Hills McCanna valve. Below the Hills McCanna valve is the Mason & Hanger-Silas Mason Co. squeeze valve through which the flow of Composition B is automatically regulated into the constant level reservoir. The structure below this is the volumetric pouring machine.

Figure 3

For our melting equipment two existing three hundred fifty gallon Dopp Kettles were modified. The modification included the installation of vacuum lids, vacuum systems, steam coils, hydraulic motor drives and the addition of a twenty four inch propeller to each agitator.

The kettle lids were fabricated from standard three quarter inch boiler heads. The various ports and openings were cut and hydraulic motors mounted on castings on top of the heads. The motors are coupled direct drive to the agitators.

Many of you no doubt remember the old arrangement? -- with the electric motor and drive belts outside the building and the long drive shaft into the kettle? It had two speeds -- slow and stop -- too often it was stopped because the product had frozen in the kettle.

A separate, water cooled hydraulic unit is provided for each kettle in the equipment room as previously stated. The agitator speed can be controlled from one half to fifty five revolutions per minute at constant torque.

The twenty four inch propeller was added to the agitator to insure good agitation in the center of the kettle.

A steam coil or "pipe cage" was added to each kettle to provide approximately seventy percent additional heating surface to increase the melt rate.

Vacuum pumps are valved to the kettles so that each pump can pull vacuum on either or both kettles. Double filters are installed in the vacuum lines of each system to prevent explosive from reaching the vacuum pumps. Vacuum of eight millimeters of Mercury can be obtained with the vacuum pumps on the kettles.

Fume and dust removal ducts for the entire melting and pouring system are connected to the original facilities.

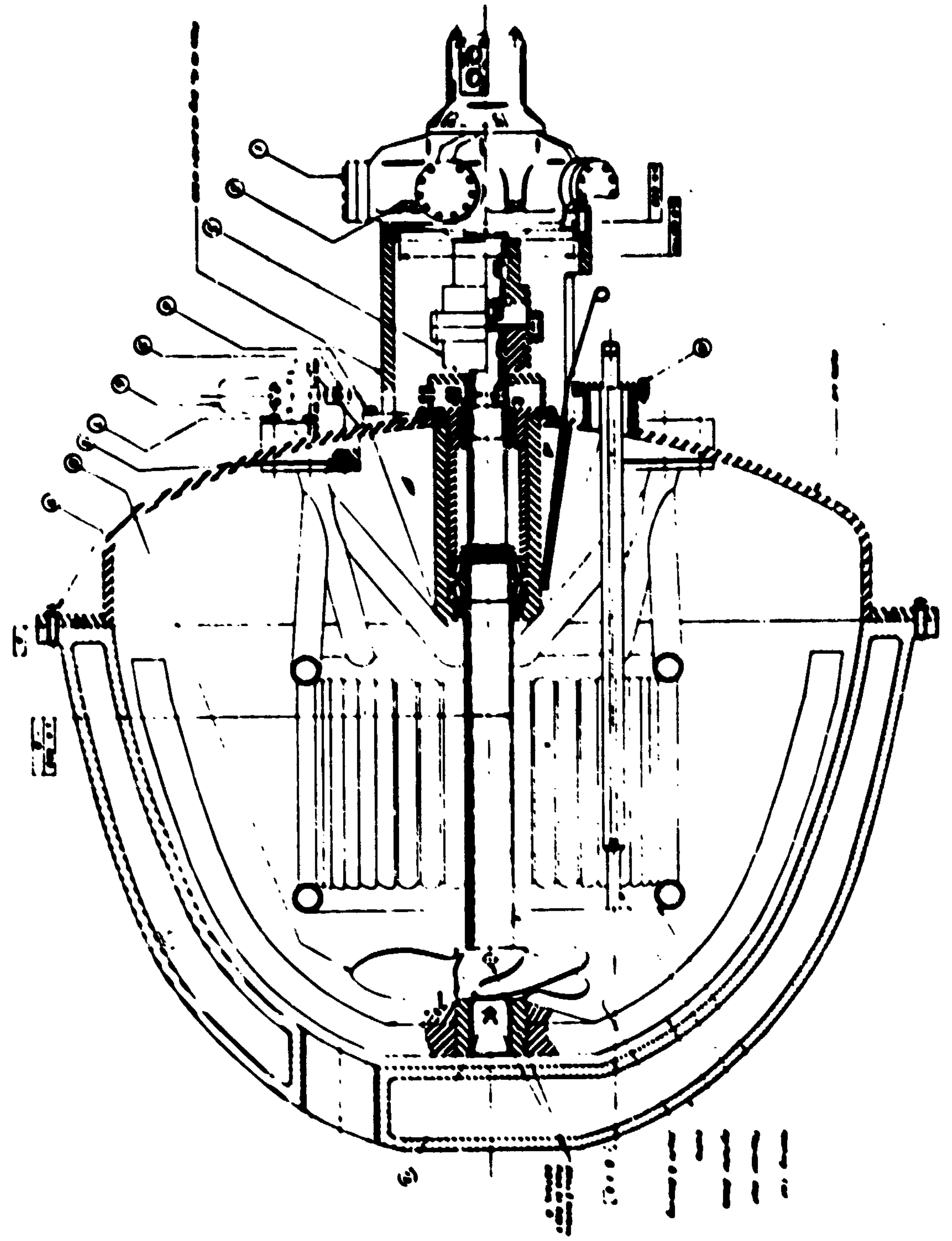


Figure 3

Figure 4 (Two kettles)

The next two slides show the equipment installation on the second floor of the melt building.

Individual control panels are installed for each kettle. Recorders for product temperature, kettle water temperature, and agitator speed are mounted on the front of each panel along with vacuum gages and control switches.

When charging the kettle with Composition B through the rubber charging hose, the steam is manually turned on in the coil and kettle jacket. When the product reaches a desired set point, the controller automatically turns the steam off in the coil and the kettle jacket. It then switches the kettle jacket to hot water, thereby maintaining the product at the desired temperature for pouring. At the start of the next cycle, steam is manually turned on in the coil and kettle jacket. Each kettle as modified, will melt four thousand pounds of Composition B per hour with a minimum settling of RDX during melt and draw off.

Figure 5 (One kettle)

This slide shows a close-up view of a modified Dopp Kettle. After the kettle has been charged with approximately four thousand pounds of Composition B, the air is evacuated for a minimum period of twenty minutes and the batch is completed ready to pour. The kettle operator notifies the pouring machine operator on the first floor through a speaking tube that the batch is ready.

He then activates a three way switch that will permit the pouring machine operator to draw into the constant level reservoir. The kettle operator cannot open the kettle valve himself nor can the pouring machine operator open it until the switch is first activated by the kettle operator. As an extra safety precaution either operator may close the valve. This arrangement precludes the batch being dropped before it is ready.

Figure 6 (Constant level reservoir)

Composition B is dropped from the kettle through the angle plug valve, the downcomer, Hills McCanna valve, squeeze valve, and pouring spout into the constant level reservoir.

The Composition B enters near the bottom, below the surface of the liquid. The liquid level is controlled by an air bubbler probe which senses back pressure and maintains a constant level of material by

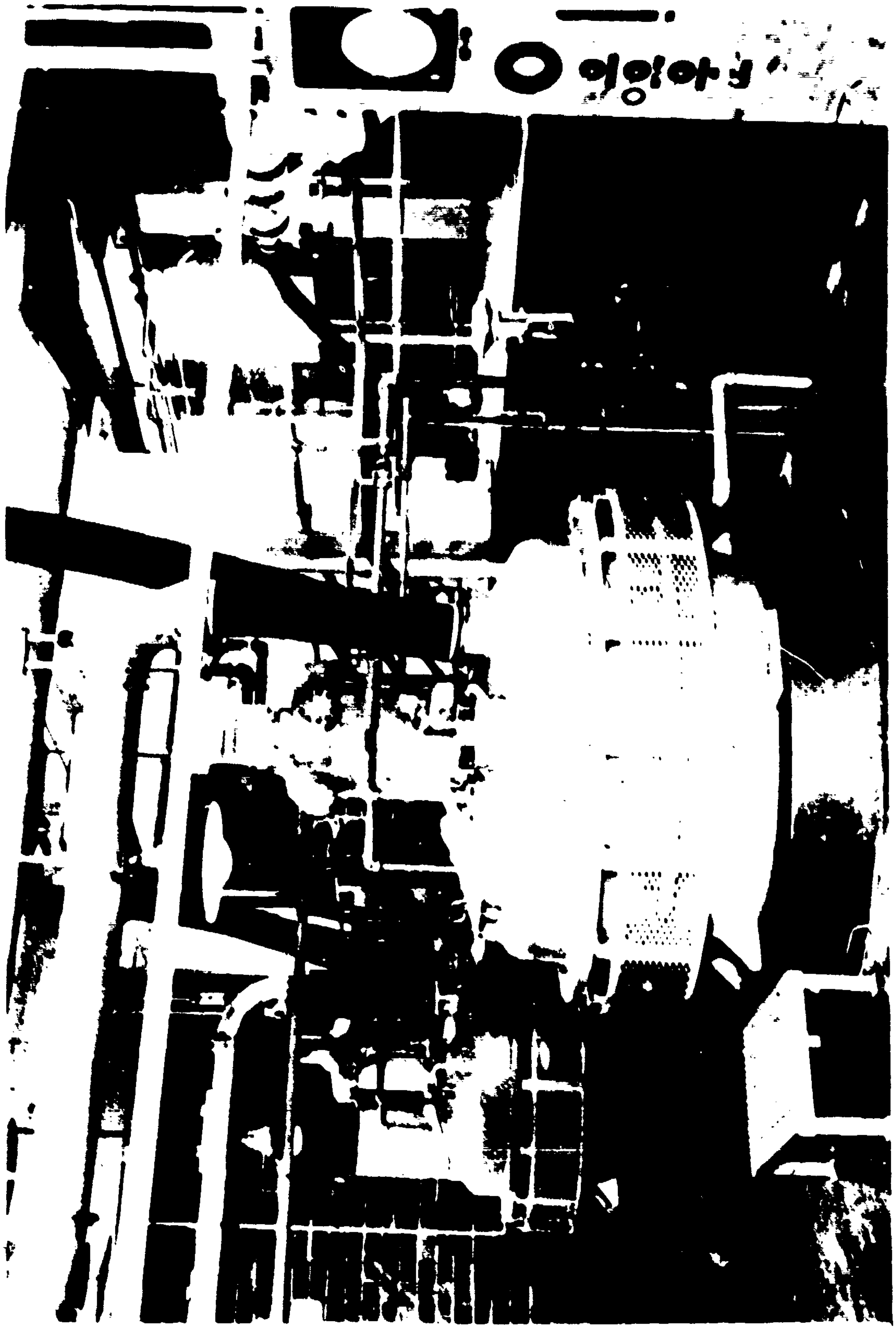


Figure 4

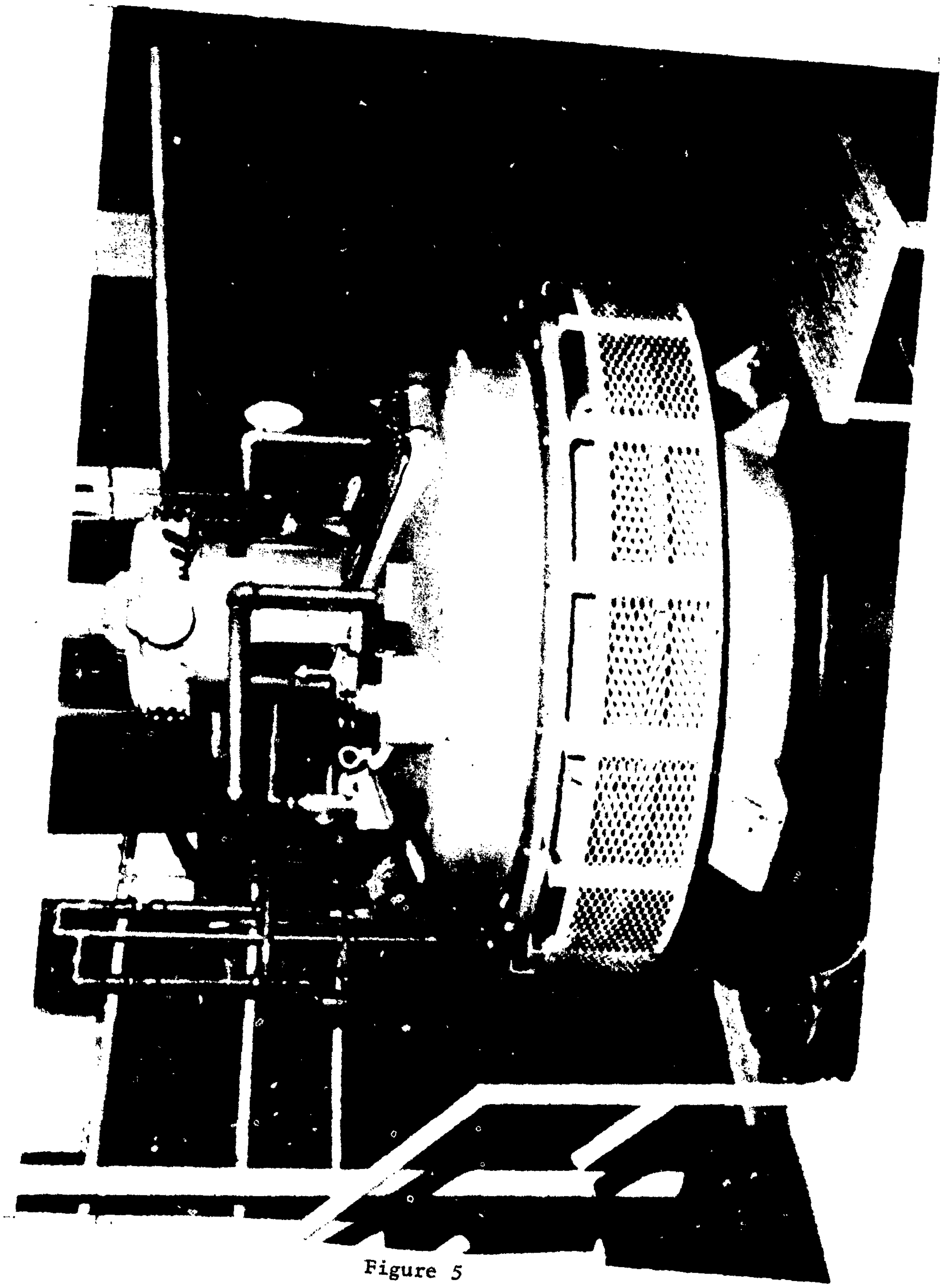


Figure 5

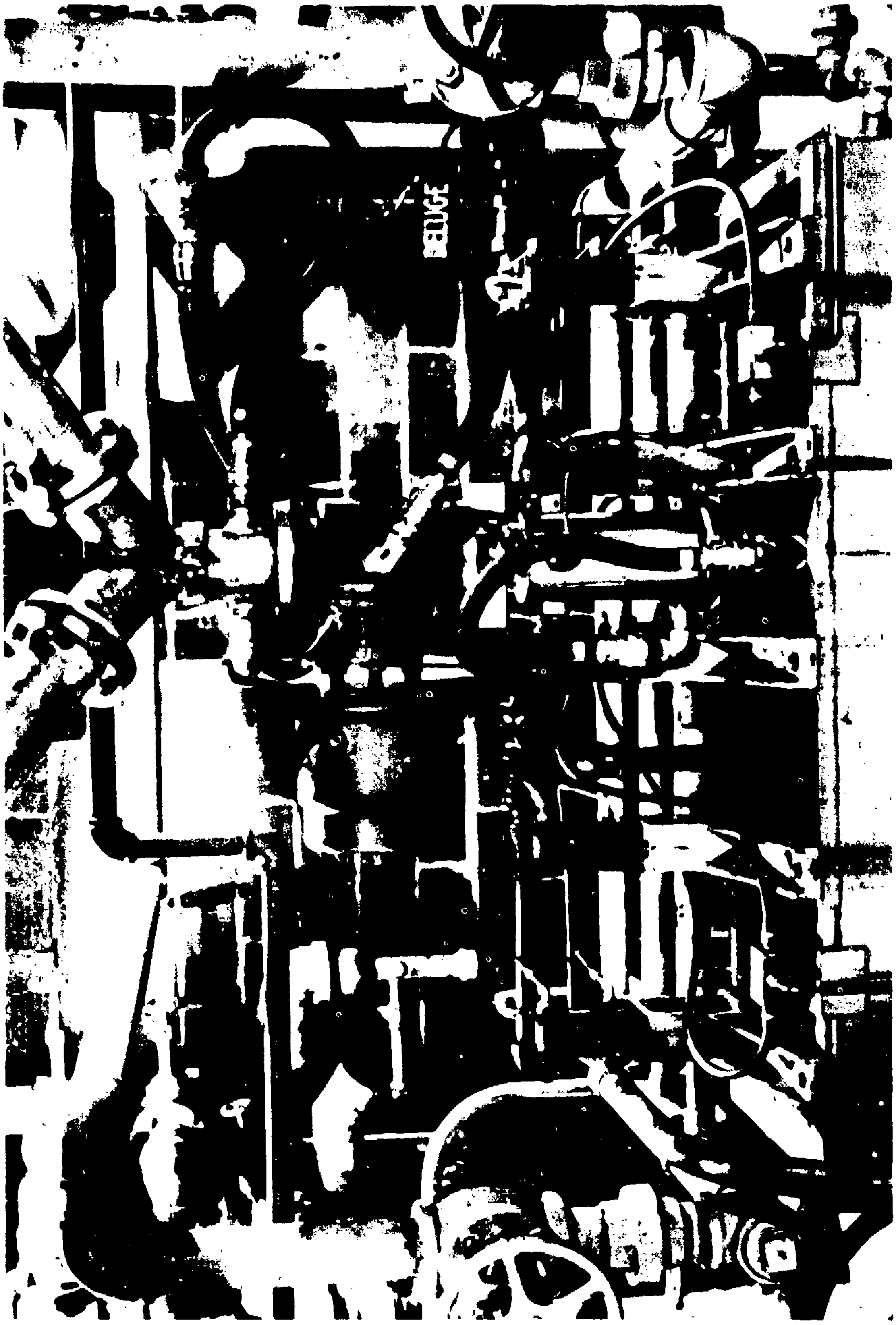


Figure 6

throttling the squeeze valve. The Hills McCanna valve provides a means of positive, emergency shut-off of Composition B.

The constant level reservoir will hold a supply of Composition B ready for pouring at any desired temperature within the range of one hundred eighty, to two hundred eight degrees Fahrenheit. The Composition B is removed from the constant level reservoir by opening the specially designed plug valves and is fed by gravity into the volumetric pouring machine.

Figure 7 (Volumetric pouring machine -- operators view)

The volumetric pouring machine is designed to measure out the proper volume of Composition B for each of fifteen projectiles. Each measuring unit has three volumetric cups and the Composition B overflows from one cup to the next. When the third cup fills, the flow is shut off and all three cups come to the same liquid level. The level in the volumetric cups is controlled by air bubbler probes similar to those described in the constant level reservoir. As a safety precaution, the operator can override any of the automatic level controls and start or stop the flow of Composition B. This can be done by manually operating the explosion proof switches on the front of the pouring machine. Heated displacement probes were designed to obtain accurate fine adjustment in the volumetric cups. There is one probe for each cup and it is used to compensate for variation in cup size or to vary the level in pouring funnels.

Composition B is controlled from the measuring units with plug stoppers similar to those used in the old volumetric loaders. As the Composition B leaves the volumetric cups it flows down the side of the funnels into the projectiles.

Three separate hot water systems were designed for use on the volumetric pouring machine. One system for each of the following:

1. Composition B downcomers.

2. Displacement probes and air bubblers.

3. Constant level reservoir and measuring unit.

The water temperature in each system can be varied from 180°F to 208°F and controlled to plus or minus 1°F.

Figure 7

A nice feature from a production viewpoint is that there is little or no scrap after the pouring operations are completed for the day. In addition, special consideration was given to the design so that there would be little if any air entrapment in the Composition B.

Figure 8 (View of tank truck at the water fill station)

In this slide, the tank trucks loaded with empty projectiles have been received at the melt building and the neoprene rubber thread protectors and the funnels have been installed in preparation for pouring. This thread protector, developed at I. O. P., eliminates the possibility of any Composi ion B leakage.

In order to eliminate seasonal fluctuations that cause variation in the cooling cycle, bath water at a maximum temperature of 180°F is used to preheat the projectiles prior to pouring. This view shows the tank trucks being filled with bath water to the desired level and being indexed into the preheat oven.

The three micro switches located above the entrance to the indexing chute were installed to shut off the indexing mechanism automatically in the event that a high funnel starts through.

Figure 9 (Exit view of pouring machine)

The preheat oven was provided to heat projectile ogives and funnels to a desired temperature for pouring. Double embossed flat heating panels were installed 1/2 inch above the funnels as the heat source. Canvas shrouds at each end of the oven were installed to contain convection currents and maintain a constant temperature inside the oven. High temperature hot water, to a maximum of 320°F, is circulated in the heating panels.

The preheat oven is long enough to enclose four tank trucks.

Indexing of the tank trailers through the preheat oven and into the volumetric pouring machine is coordinated by the pouring machine operator with the operator at the water fill station.

After filling the projectiles the cart is indexed out of the volumetric, another cart of fifteen projectiles is indexed into position for filling, and the cycle is repeated.

Immediately after pouring, each tank truck is moved by electric tow truck to the conditioning oven.

Figure 8

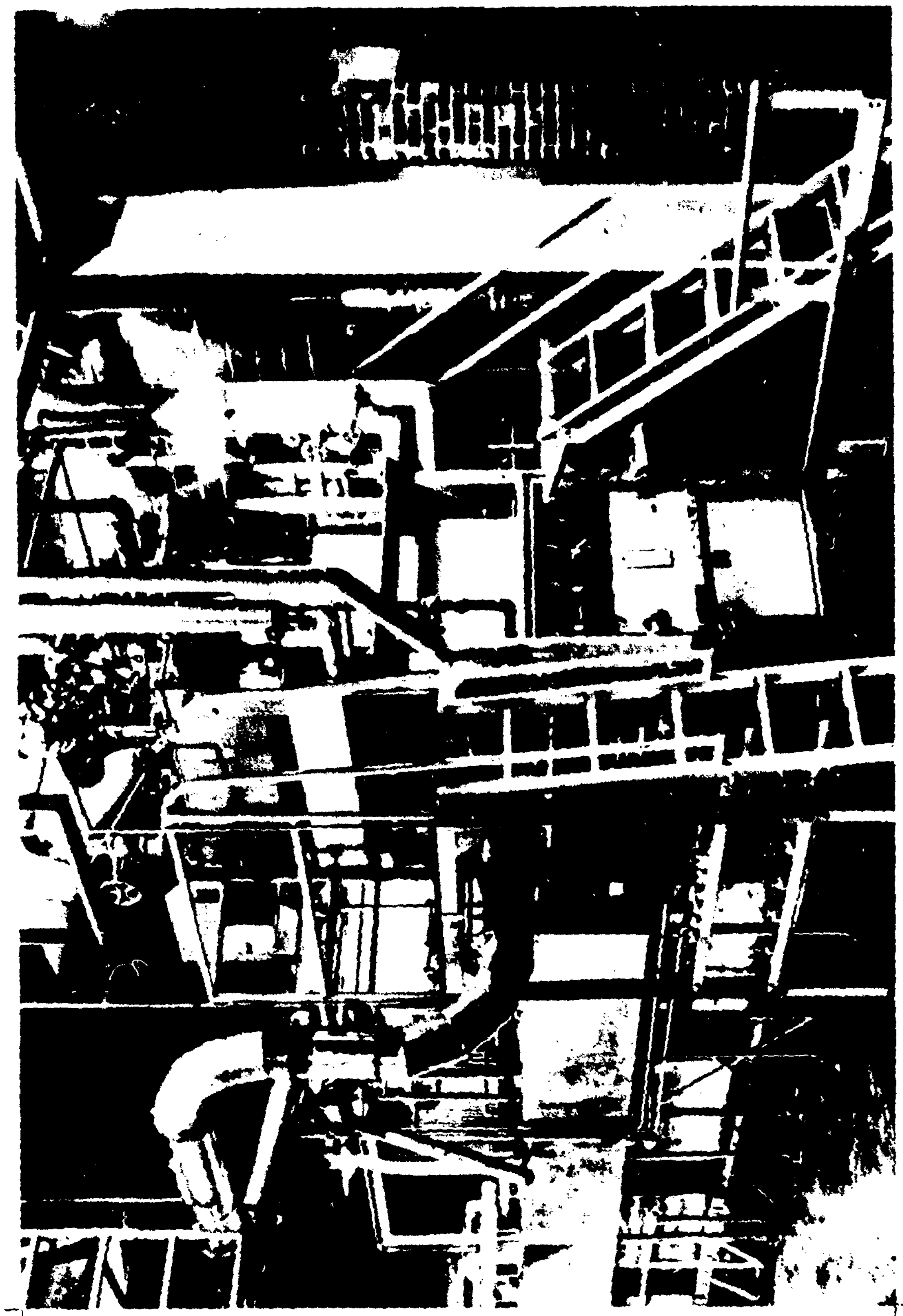


Figure 9

Figure 10 (Tops of ovens looking west)

As previously stated, five conditioning ovens are installed and space allotted for three additional ovens if the need should arise. The ovens are seventy-two feet long, four feet wide and approximately ten feet high.

The oven. "e designed to hold twelve tank trucks.

The trucks are placed in the oven as they are indexed out of the volumetric pouring machine and remain in the oven approximately 12 hours to complete the cooling cycle.

This slide shows the method of circulating bath water in the tank trucks. Beside each tank truck in the oven is a bath water supply line, and throttling valve to control flow. The water level is preset by means of stand pipes beside each truck connected by a rubber hose mounted on each truck. The water overflows the level by gravity into the open trough back to the underground reservoir outside the building. The bath water circulating system is designed to circulate water to the tank trucks at any temperature up to a maximum of 160°F.

Figure 11 (End view of oven with shells and funnels in position)

The oven heat sources were assembled from prefabricated single embossed panels, contoured to enshroud the funnel and shell ogive with 1/2 inch clearance. The use of embossed panels eliminated the long sections of piping used in the past in other ovens of this type. The only piping required was headers on the end of each oven. This arrangement allows the heat sources to expand toward the center of the oven. The heat sources are used to keep the Composition B molten in the funnel neck to insure feeding during the cooling cycle. High temperature water up to a maximum of 320°F is circulated in the panels. Each oven has its own water system thus adding flexibility to the system.

Figure 12

This slide is a view of the outlet ends of the ovens showing heat sources and bath water circulating system.

Figure 13

This slide shows the underground reservoir capable of holding 50,000 gallons of bath water. The reservoir was designed with the capability of operating one half of the reservoir while cleaning the other half. Water is changed from one side to the other with a diverter.

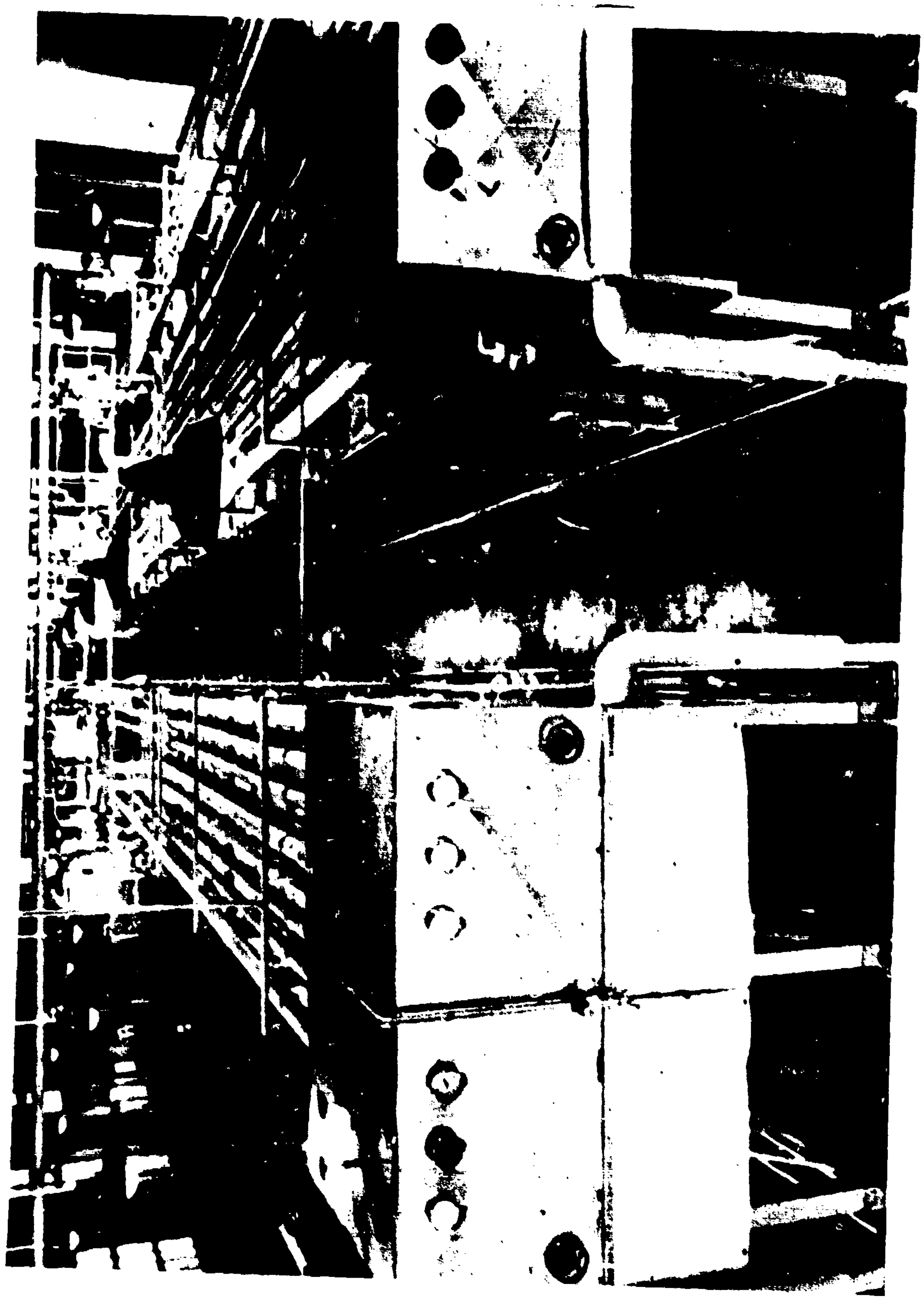


Figure 10

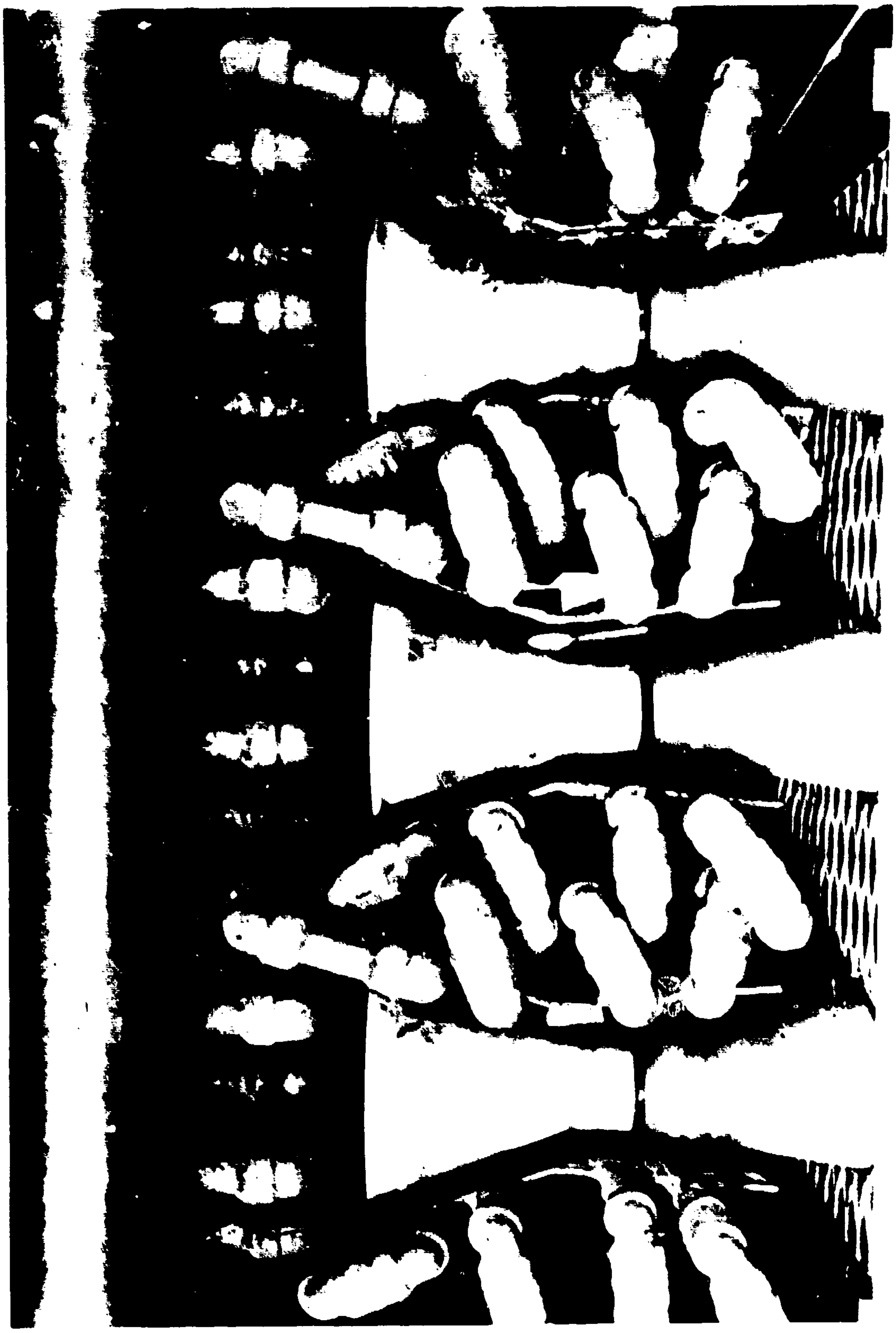


Figure 11

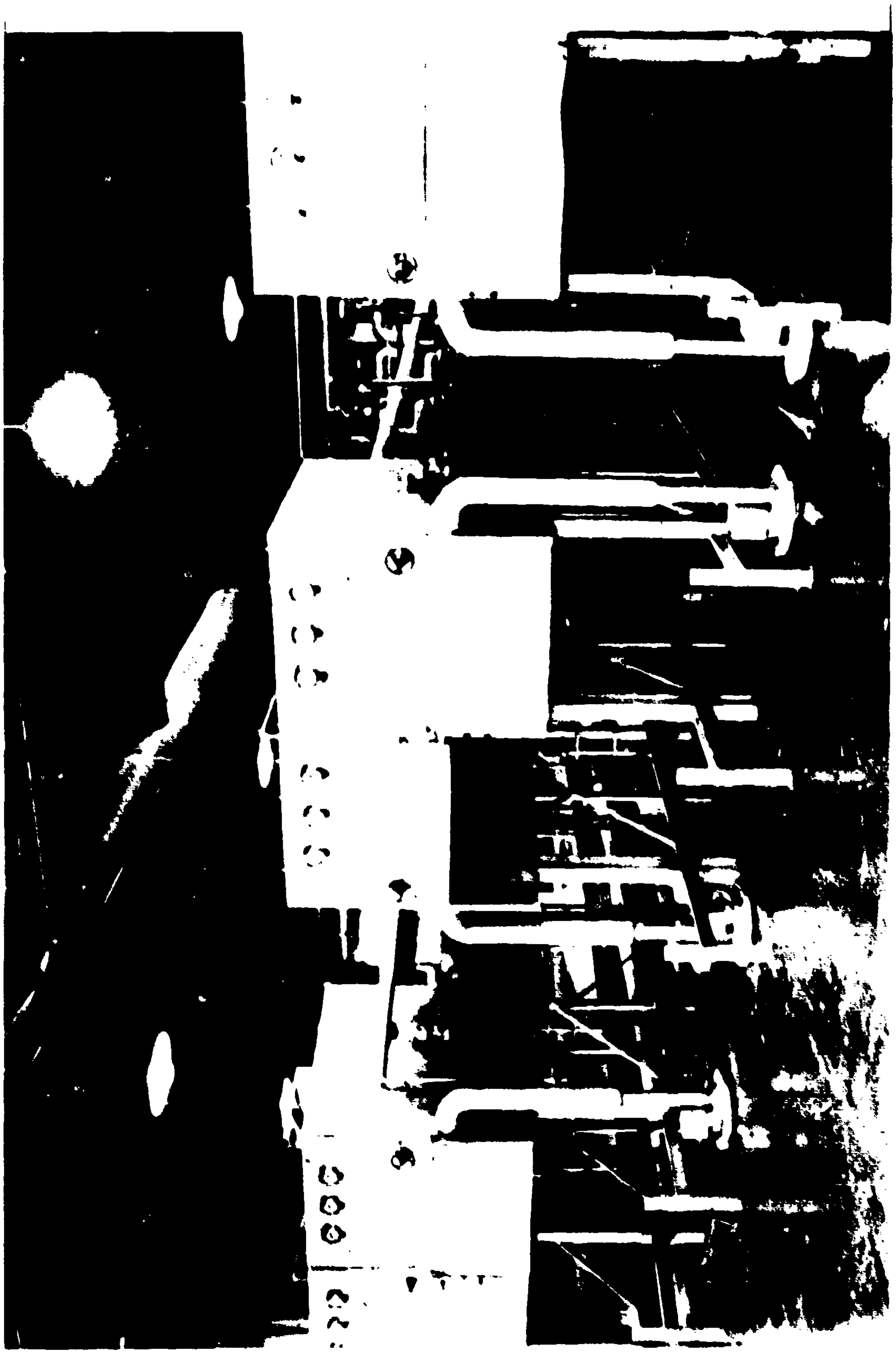


Figure 12

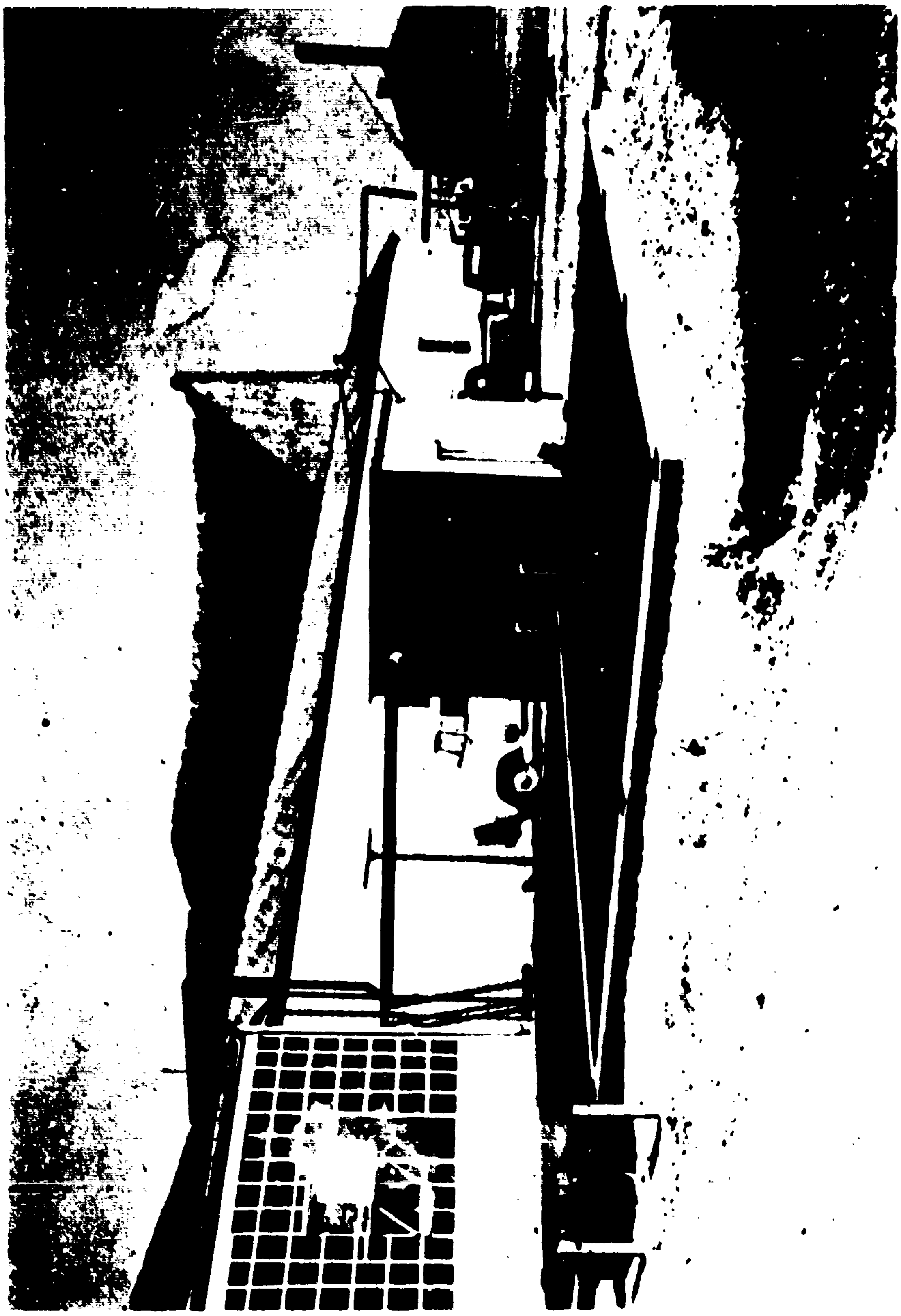


Figure 13

The heat exchanger and pumps for the bath water circulation are located in the bath water pump house.

Figure 14 (View of winch with ovens empty)

The tank trucks are pulled into position in the conditioning oven by a portable air powered cable winch. The winch is remotely controlled at the inlet end of the oven. This somewhat simple method of loading the oven is very economical and eliminates conveyors and resulting cleaning problems. The trucks are removed from the ovens and towed directly to the fuze well drilling operation.

SUMMARY

The production process made possible by this equipment eliminates the need for most of the troublesome little operations we used to go through to complete the cooling process. Cut down, add pour, probing, blending, venting and top off operations are no longer necessary. With this method you pour it, cool it and the cast is completed.

From the safety viewpoint the number of personnel required in this process is greatly reduced because of the deletion of the aforementioned operations therefore eliminating unnecessary exposure of personnel. Last but not least is the peace of mind it affords with respect to quality. You no longer expect to get reports from X-ray on cavitation, pipes and porosity and you may rest assured that if the procedure has been followed faithfully, the shells will meet the acceptable quality level with a greater degree of safety.

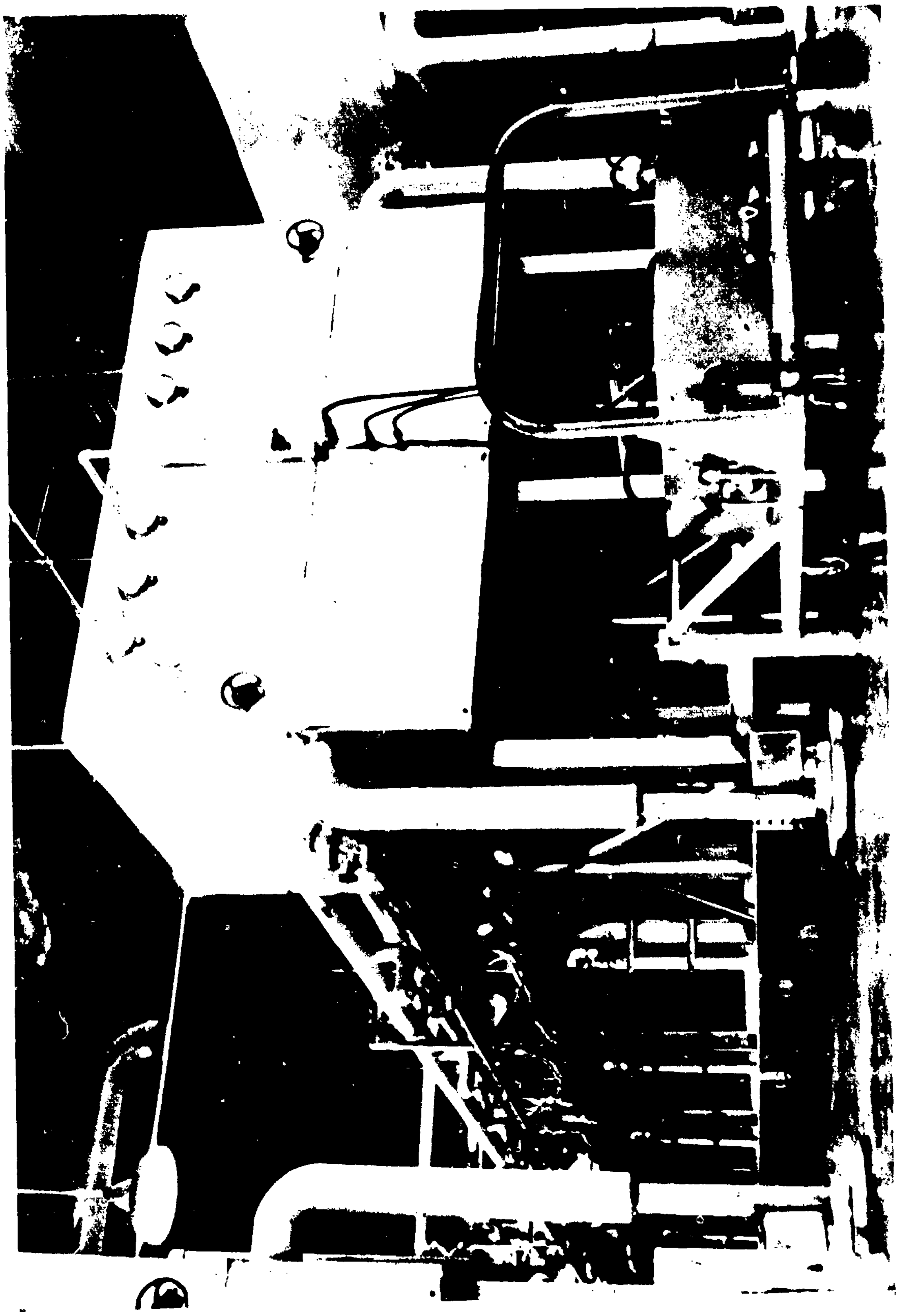


Figure 14

SAFETY IN PYROTECHNIC MANUFACTURE

Mr. W. C. McCay
Safety Director, Longhorn Army Ammunition Plant
Marshall, Texas

In recent years, the manufacture of pyrotechnic items for military use has taken on new concepts and requirements as a result of the SEA engagement. New items in the pyrotechnic family have been required to combat an enemy in a new and challenging environment. Existing items have had to be modified to meet the specific need. Production rates have soared from a few thousand units per month for a single item to a requirement of 100,000 units and upward per month. With few exceptions, the quantity of pyrotechinc items required in previous years was provided by private contractors at privately owned plants.

Because of competitive bidding, low quantity demand, and uncertainty as to length of contract, private contractors were never able to provide facilities and equipment necessary for high production rates. Also, demands were not great enough for the Department of Defense to provide special facilities, or Plant, that could produce the items on a high rate of production similar to that required for conventional ammunition.

Early in 1963 the picture began to change. Ammunition Procurement and Supply Agency, Joliet, Illinois selected Longhorn Army Ammunition Plant, Marshall, Texas as the site for production of the M-125 series of hand signals. The Plant is a GOCO facility with Thiokol Chemical Corporation as the operating contractor. At the time of selection, the Plant

was engaged in manufacturing Rocket Motors for the Army. Items included the Nike Hercules, Sergeant, Falcon and Pershing Motors. Part of a facility constructed in 1951 for manufacture of a pyrotechnic item (M-120 Photoflash Bomb) was reactivated for manufacturing hand signals. By early Spring of 1965, the Plant was requested to convert and reactivate additional facilities for manufacturing 105mm and 155mm Illuminating Shells, 4.2" Illuminating Mortar, in addition to Hand Signals. Immediately upon going into production of these items, schedules and capability rates were increased to requirements equal to that of conventional ammunition. Other items were added in fast succession to include the 60mm and 81mm Illuminating Mortar Cartridges, AN/ALA-17 Flare, and XM40 Anti-Intrusion Button Bomblet.

To meet the desired schedule rates for these items, the operating contractor, with the aid of outside vendors, had to design new automatic and semi-automatic equipment, convert existing machines and tools, and substitute, or replace, obsolete equipment used in the pyrotechnic industry. New methods and procedures had to be conceived and approved. Safety had to be implemented into the scheme as required. Even though optimum safety has not been obtained in all phases of operation, there are some features that we think worthy of interest and discussion at this meeting.

The first item I would like to discuss is a material we use for flash shields. In pyrotechnic production, it is necessary to have a transparent material with high temperature resistance and strong durability as to impact and tensil strength. Several plastic companies are now producing a polycarbonate sheet that will meet this requirement. One of the first uses for this material was the face shield used by astronaut White in his space walk.

Picatinny Arsenal conducted tests of the material to determine its adequacy for protection against flash fires. The following information is extracted from correspondence received from that Arsenal:

a. Polycarbonate sheets of different thicknesses were procured from the Rowland Products, Inc., Kensington, Conneticut to perform tests to determine the adequacy for use in asbestos hoods.

b. Although these sheets of polycarbonate were not put into hoods due to their shape, they were subjected to the flame of a fast burning pyrotechnic composition. The sheets used for this test were .080 and .093 in thickness. They were placed against a wooden box at about the same distance from the powder that an operator would be while working with this material. The test was actually more severe than would be experienced at an operation. The weather was windy and the flames were blown directly against the sheets.

c. The sheets were extensively charred and received several slight, fine cracks but remained intact. From results of the tests conducted on polycarbonate, it is concluded that this material is substantially adequate for protection against a severe flash fire, and it may be used in asbestos hoods and possibly nitrometer masks. The cost of polycarbonate is comparable to cellulose acetate when procured in the sheets. Sheets 1/4" thick cost approximately $2 per pound.

Shown here on slides are a few examples of the use of this material in our pyrotechnic production. (Figures 1 thru 8). Sheets of material procured for our use are 4' x 8' x 1/4" and can be sawed, machined, or bent into desired shapes. The tensile strength of the material will average 8,500 PSI at room temperature. Even at 250°F, when many other thermoplastics are formless masses, a 1/8" thick sheet will still exhibit a tensile strength of 6,000 PSI. Average Izod impact strength of 14 foot pounds per inch of notch are exhibited by 1/8" thick specimens. This means that a sheet only 5/16" thick will bounce off a .22 caliber long rifle slug fired at 19 feet; a .38 from 15 feet; and a .45 caliber from 50 feet. An untinted sheet of the material has a luminous transmittance of 86% in a 1/8" thickness. This compares to 92% for glass.

The second item for discussion involves mixing operation changes which we believe have been good safety improvements. In the mixing

Figure 1

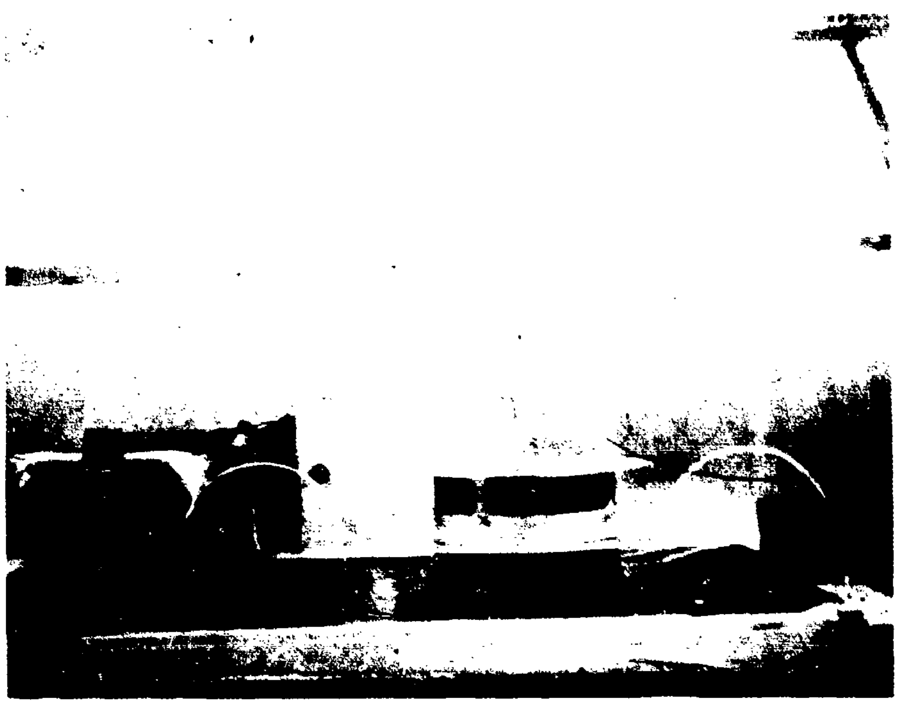


Figure 2

Figure 3

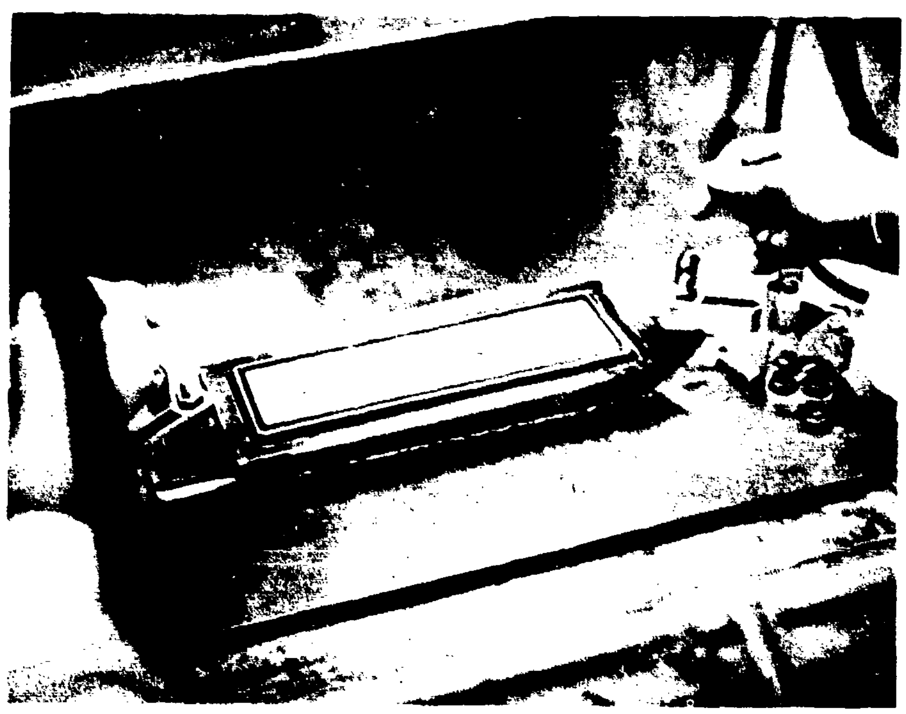


Figure 4

Figure 5

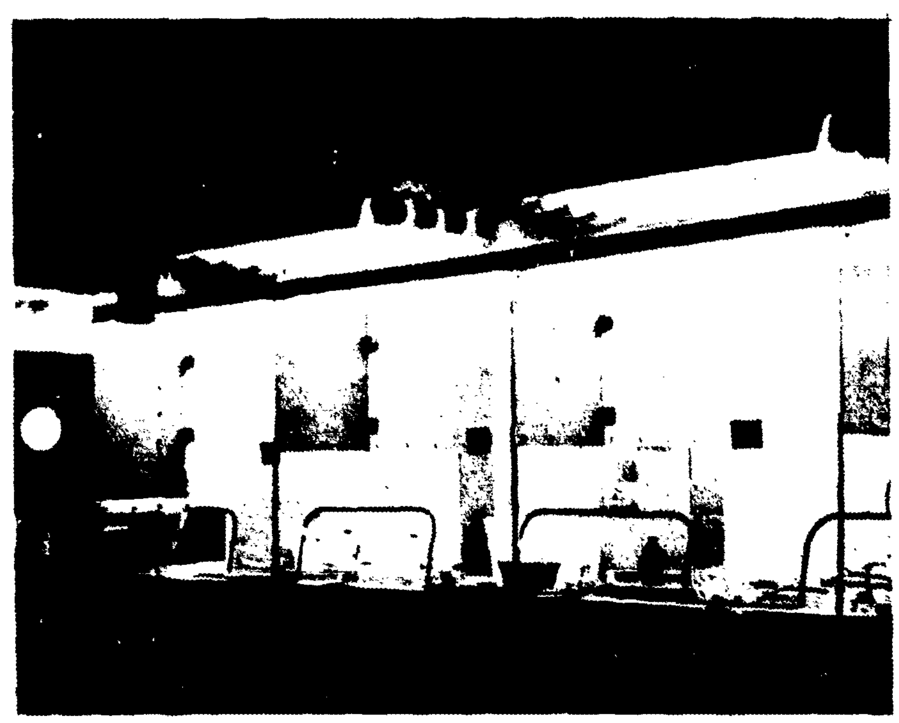


Figure 6

Figure 7

Figure 8

operation there is always danger of the mixing blades coming in contact with the bowl surface or some foreign object entrapped underneath the mixer blade and causing undue friction between the mixer bowl and the object. To combat this hazard in the operation of our Simpson-Muller type mixers for illuminant compositions, the operating contractor has attached a teflon wiper to the leading edge of the blades with zero clearance between the teflon and bottom and side of the bowl. The blade section that wipes the center shaft is also equipped with teflon. The 1/4" thick teflon is attached to the blade with rivets and a metal strip for reinforcement. The teflon extends approximately one inch beyond the blade edge thus permitting greater clearance to be maintained between metal blade and bowl. This modification, in addition to the clearance factor, assures a better mixing of all materials and leaves the mixer cleaner after dumping. (Figure Nos. 9 and 10)

Use of non-flammable material for cleaning mixers is another noteworthy safety feature. Acetone has been a prominent cleaning agent in the pyrotechnic industry for several years. Several fatalities were experienced last year from using aceton in cleaning mixers. Through a series of tests, the operating contractor at Longhorn has found that two substances - methlyene chloride and phosphate ester mixed in proportions with sawdust, make an excellent solution for cleaning mixers that are contaminated with pyrotechnic materials. (Figure No. 11)

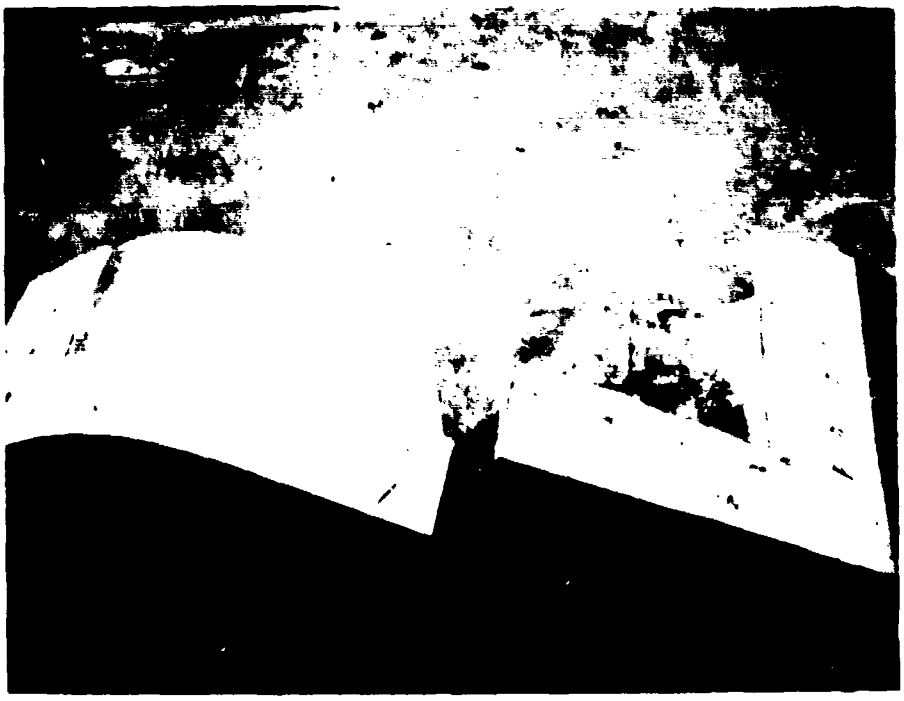


Figure 9

Figure 10

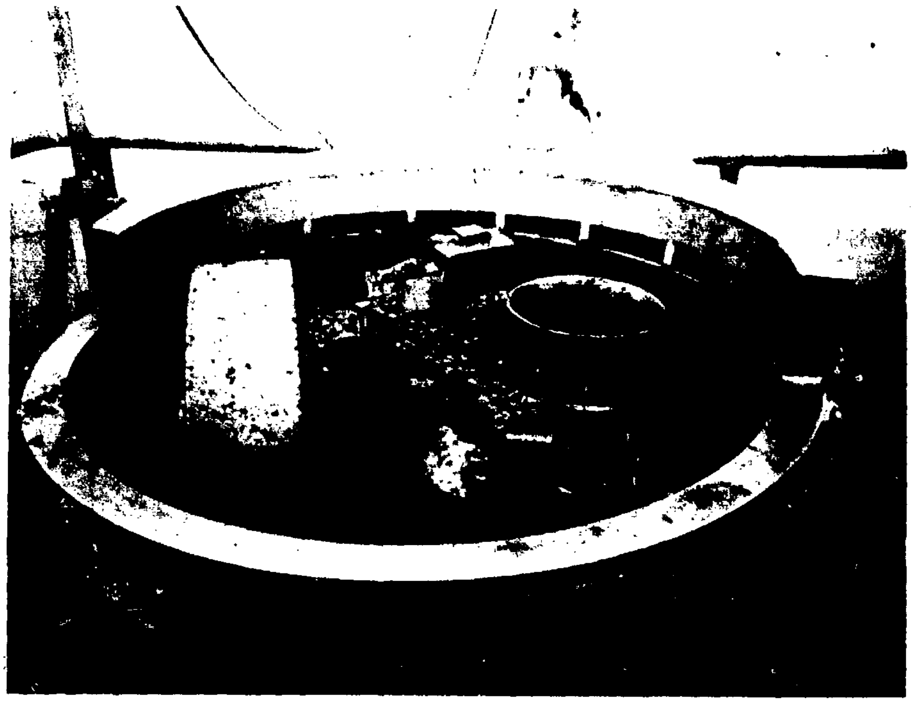


Figure 11

Methlynene chloride is preferred over other materials because of the economic factor. A mixture of the solution is put into the mixer and the mixer is operated for approximately 10 minutes, dumped, rinsed with water, and wiped down with a rag dampened with acetone. The fact that the blades are equipped with teflon wiper makes cleaning easier as only a small amount of residue is left in the mixer after the mixing cycle.

In a previous presentation by Mr. C. D. Attaway, Thiokol Chemical Corporation, a new type of material for protective clothing planned for use at Longhorn was discussed. In the next few slides, (Figure Nos. 12 thru 20) I will show the present protective clothing required to be worn by operators in the most hazardous areas. Every effort is made to protect the operator against fire which is the paramount hazard in the pyrotechnic industry.

In the next set of slides, I will briefly show examples of layout of work areas, other safety features, and especially designed equipment that has been required to meet a high production rate. (Figures 21 thru 40).

Figure 12

Figure 13

Figure 14

Figure 15

Figure 16

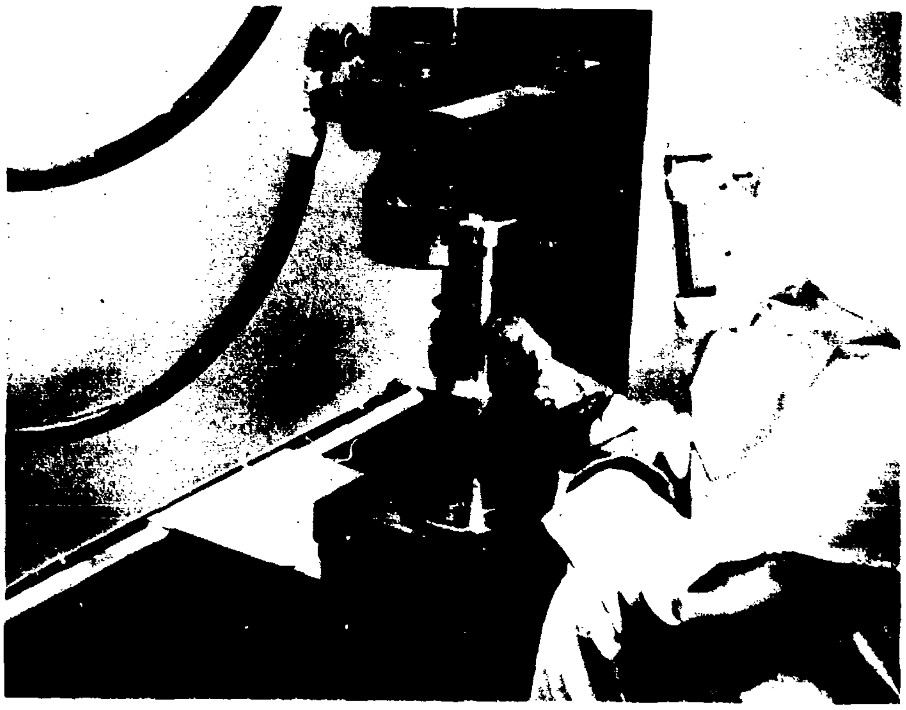


Figure 17

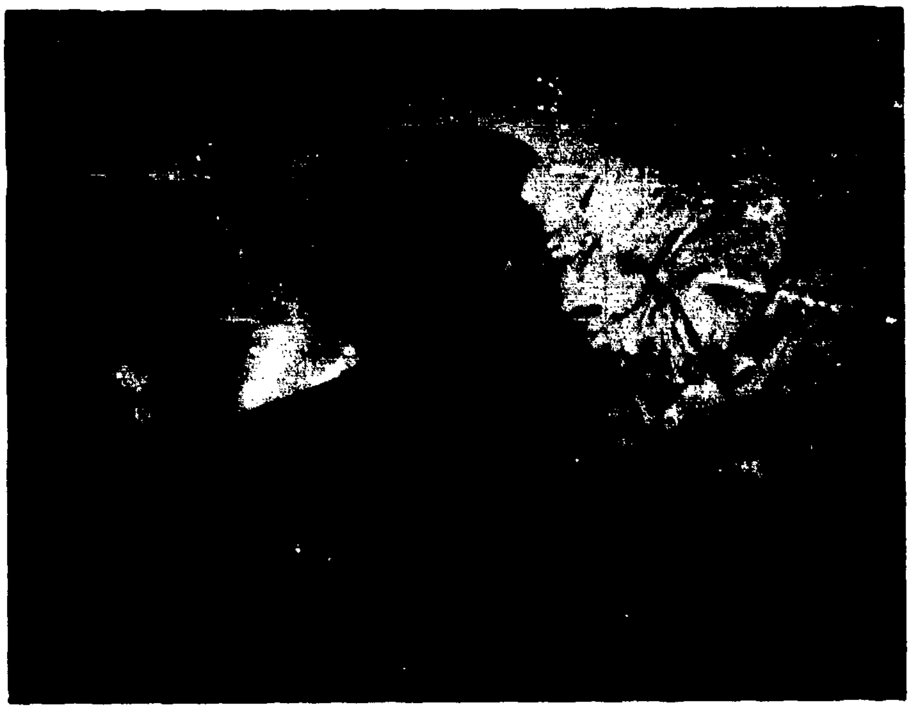


Figure 18

Figure 19

Figure 20

Fig. 21. Aerial View of Plant 2 Pyrotechnic Area

Figure 22. 105MM Illuminating Shell Final Assembly

Figure 23. Same as Figure 22

Figure 24. 81MM Mortar Assembly Line

Figure 25. Propellant Increment Assembly for Hand Signals

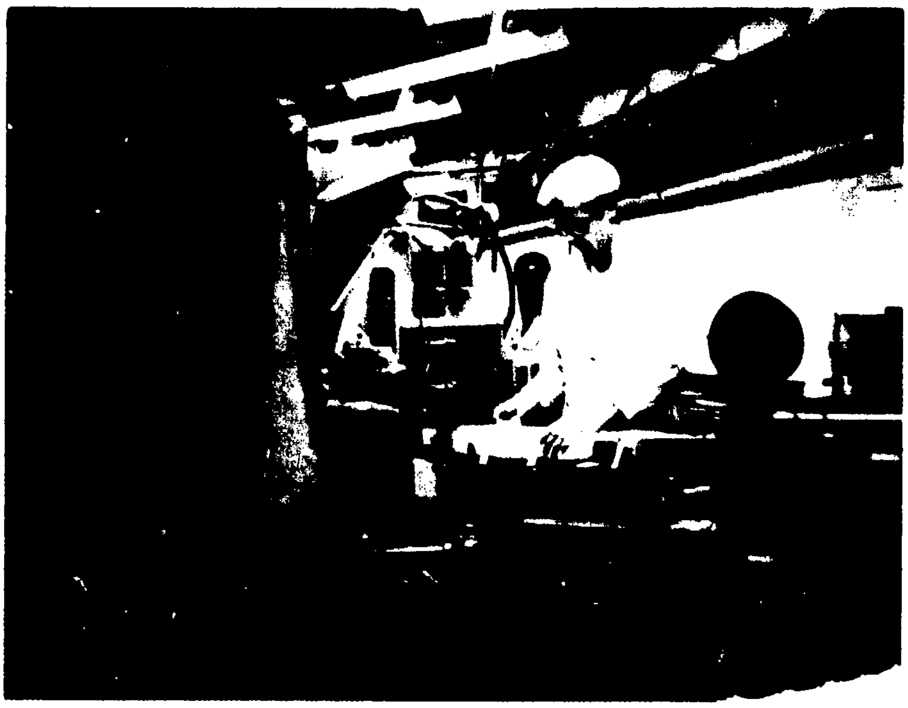


Figure 26. Drill Machine for Twist and Shear Pin Holes

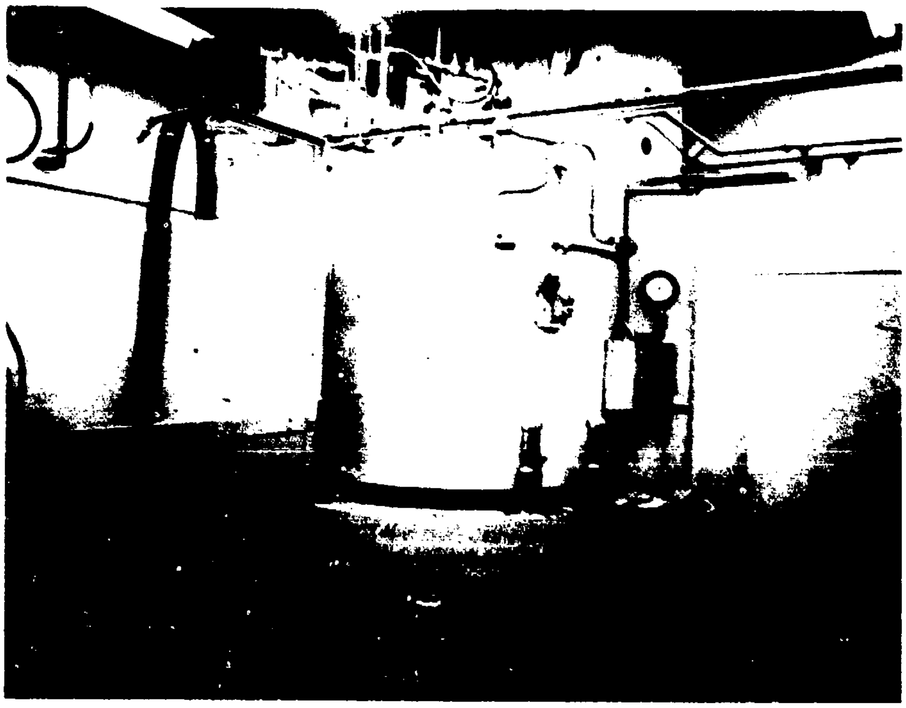


Figure 27. Consolidation Press for AN/ALA-17 Flare Pellet

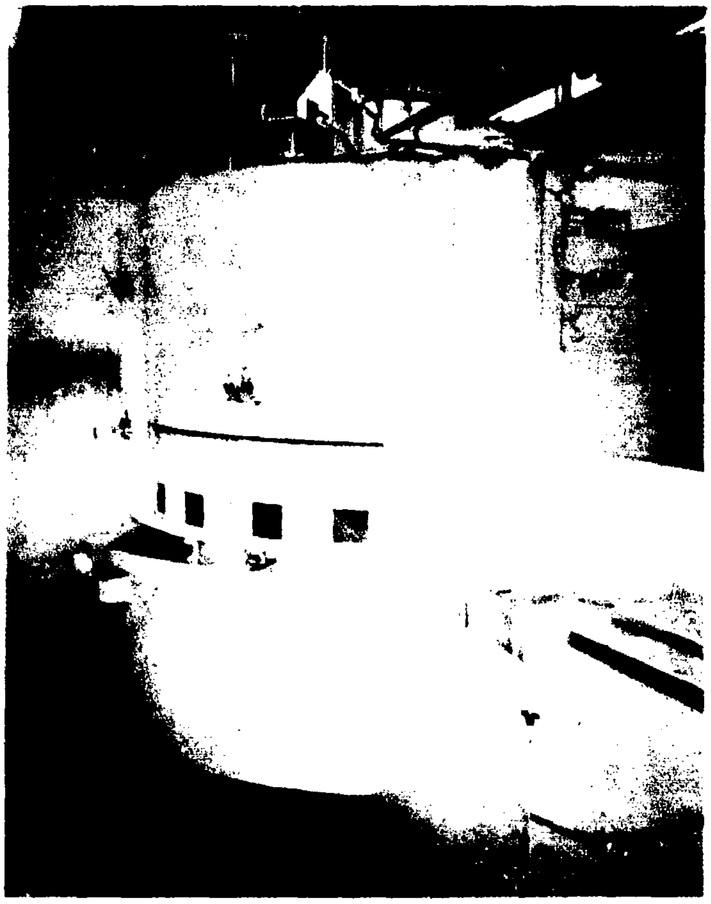


Figure 28. Consolidation Press for AN/ALA-17 Flare Pellet

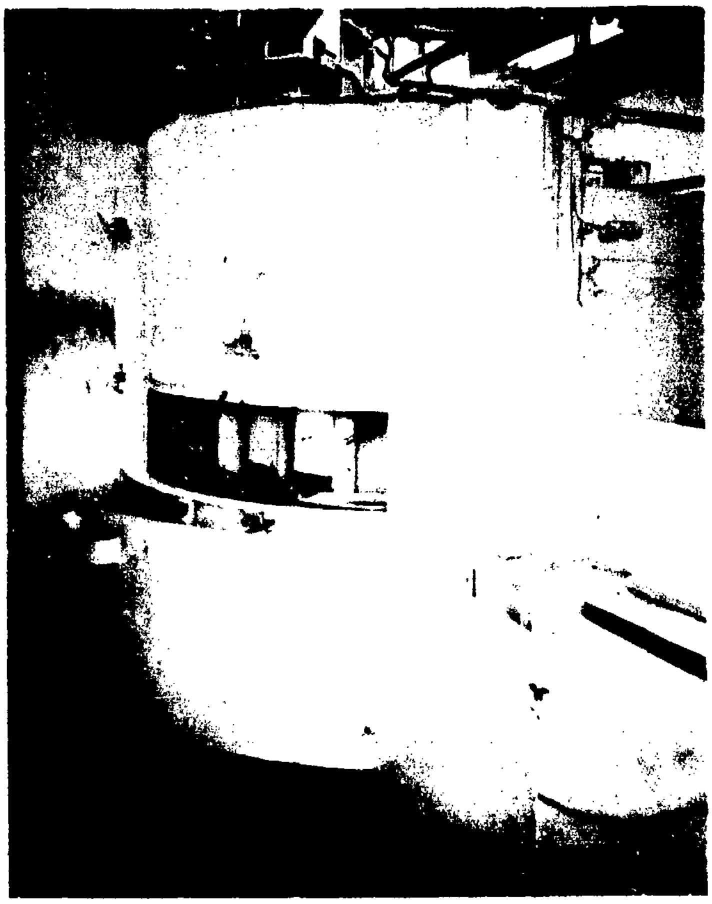


Figure 29. Consolidation Press for AN/ALA-17 Flare Pellet

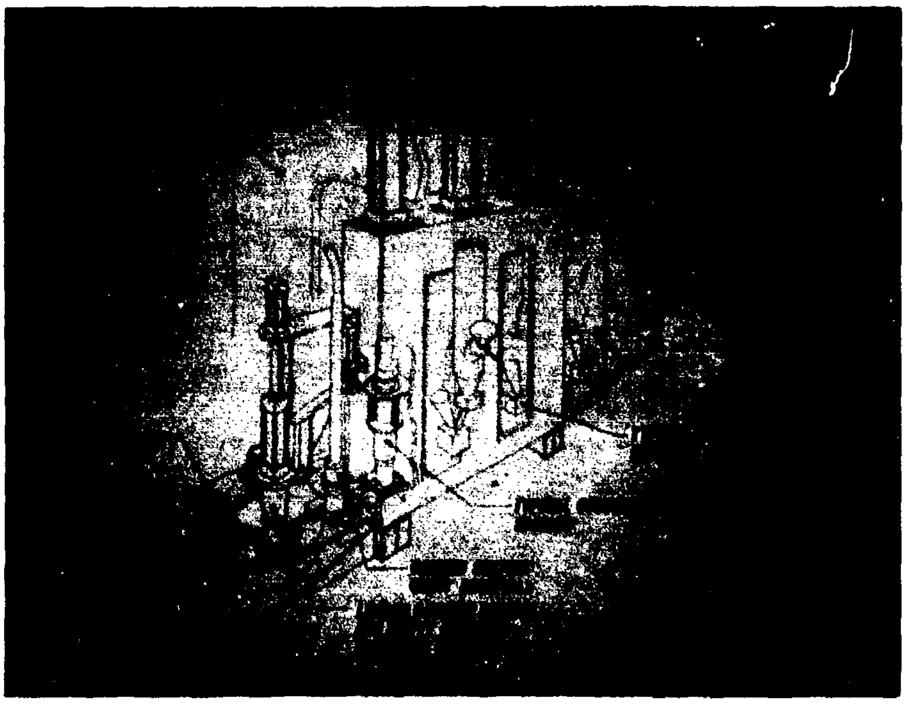


Figure 30. Cannister Consolidation Press for 105MM Pictorial Sketch

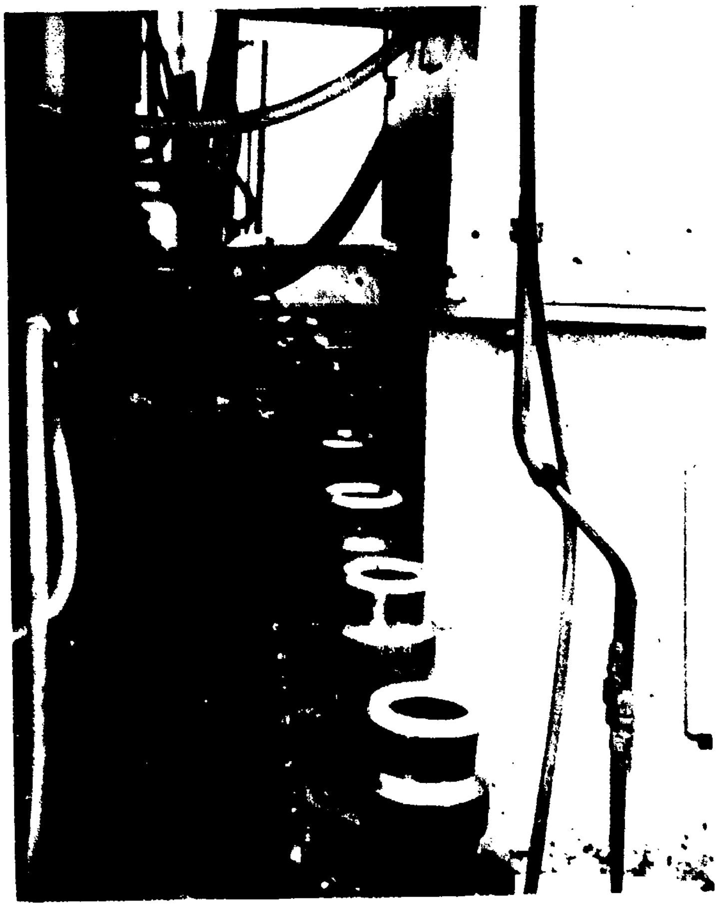


Figure 31. 105MM Consolidation Press Showing Multi-Dies at Rear

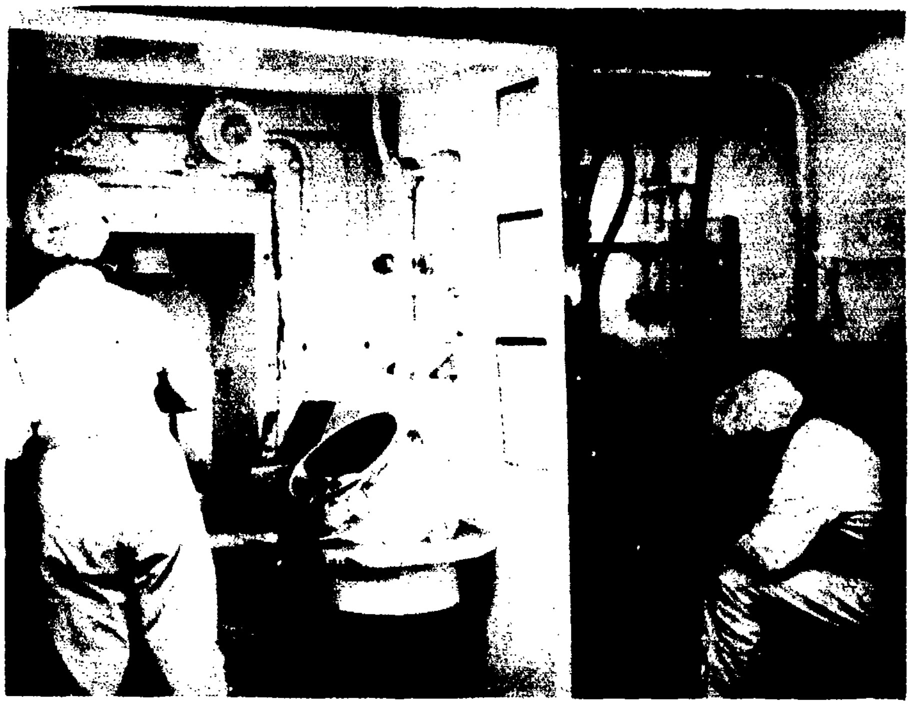


Figure 32. 105MM Consolidation Press Canister Extraction Station

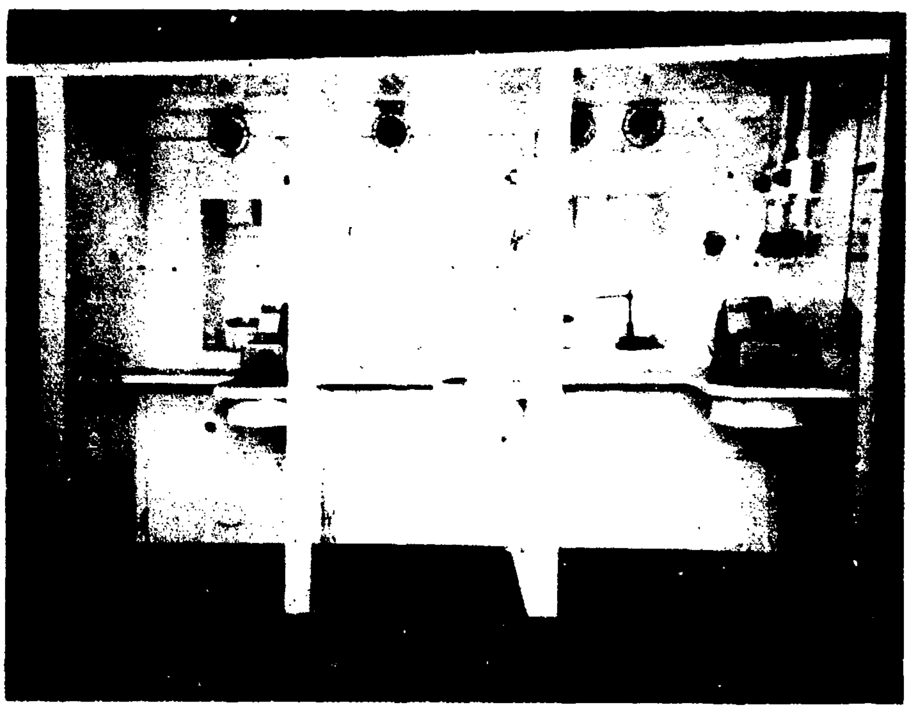


Figure 33. 105MM Consolidation Press Canister Increment Loading Stations

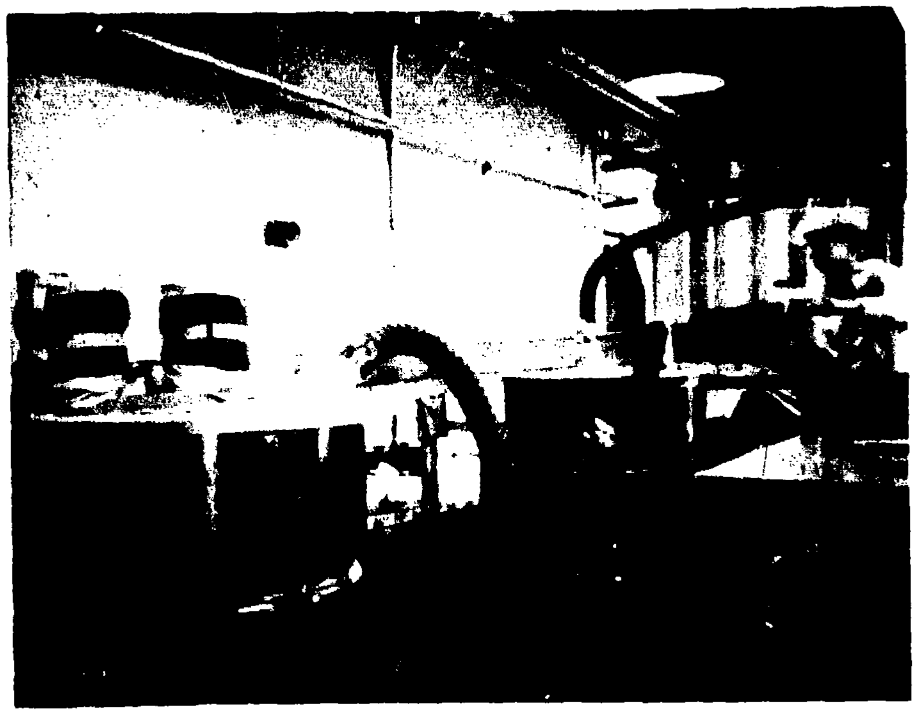


Figure 34. Wet Water Vacuum Collector

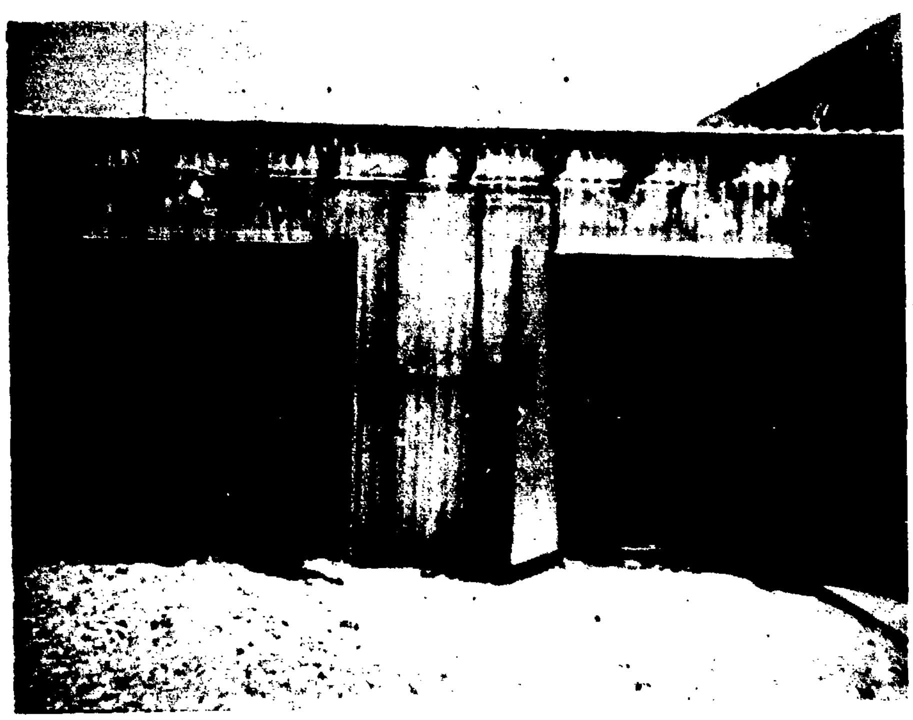


Figure 35. Emergency Exit Doors

Figure 36. Emergency Exit Doors

Figure 37. View of Weak Wall Construction for Consolidation Press Bldg

Figure 38. Posted SOP With Pictorial View of Operation as Performed

Figure 39. "Kelly" Safety Door

Fig. 40. Protective Holder for AN/ALA-17 Flare Pellet at Gaging Operation

[redacted]

NEW IDEAS IN EXPLOSIVES MELTING

Mr. J. M. Richardson
Safety Director, Sperry Rand Corp.
Louisiana Army Ammunition Plant
Shreveport, La.

At Louisiana Army Ammunition Plant, we recently underwent a major modernization in the melt unit of our line for loading 155mm shells. Gone are the old cast iron kettles and melt grids, the hot spots and cold spots, and numerous other temperature and cleaning problems. Today, we have new stainless steel kettles, redesigned aluminum grid melt units, Syntron vibrators, and a completely new automatic temperature control system.

Besides wanting to eliminate temperature control and cleaning problems, other factors were equally paramount in our thinking. These were:

1. Improved Safety
2. Increase production
3. Reduce loading costs
4. Better quality of the end product (fewer rejects)

Our first consideration for this modernization was naturally directed toward maximum utilization of the existing facilities. What changes were necessary and what could remain as is? Due to the type of construction and building layout, no change was made in transporting the raw explosive in hoppers from the screening building to the third floor of the melt building. All other systems and/or equipment are either new, redesigned, or rehabilitated.

The design of the Syntron vibrators was changed in order to give better distribution of the raw explosive over the grids in the grid melt units. The grid melt units were enlarged and redesigned to give faster melting. Time did not permit for working out designs for installation of stainless steel grid units; however, designs have now been formulated and future installations will be of stainless steel. The present grids, fabricated out of aluminum by a local manufacturer, are satisfactory and have the non-corrosive and non-sparking characteristics desired. The grids are designed, of course, to use only 5 pounds of steam pressure which allows for fast melting of the flake explosive. The grid reservior is made of mild steel and is jacketed in such a manner as to avoid cold spots in the unit. (Photos 1 and 2)

Extensive efforts went into designing the stainless steel kettles. The inside contact surfaces of the kettles are made of 316 stainless steel because it is less porous than other types of the 300 series. The other parts of the kettles are made from 304 stainless steel for ease of cleaning, and for its non-sparking and non-corrosive characteristics. The kettles were designed with removable hot fingers to give maximum heating on TNT, yet removable so these kettles could be used for Composition B and other types of explosives that have funnel cones which require melting in kettles (Photo 3). The agitator was designed with 6 prong blades set at 45° angles and with hot finger blades pitched opposite at 45° angles to work the product in and out through the agitator. It was decided to use

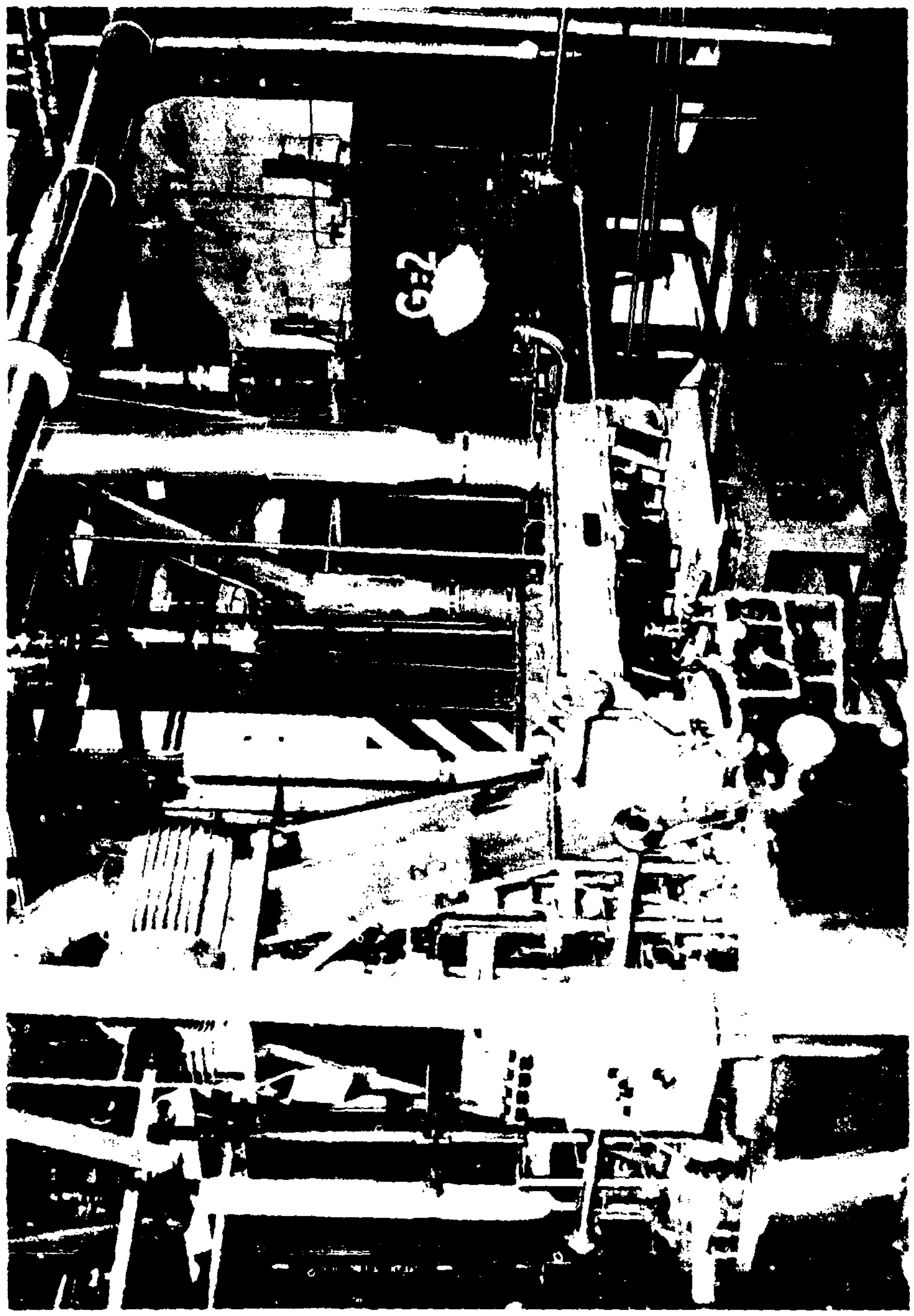


Photo #1

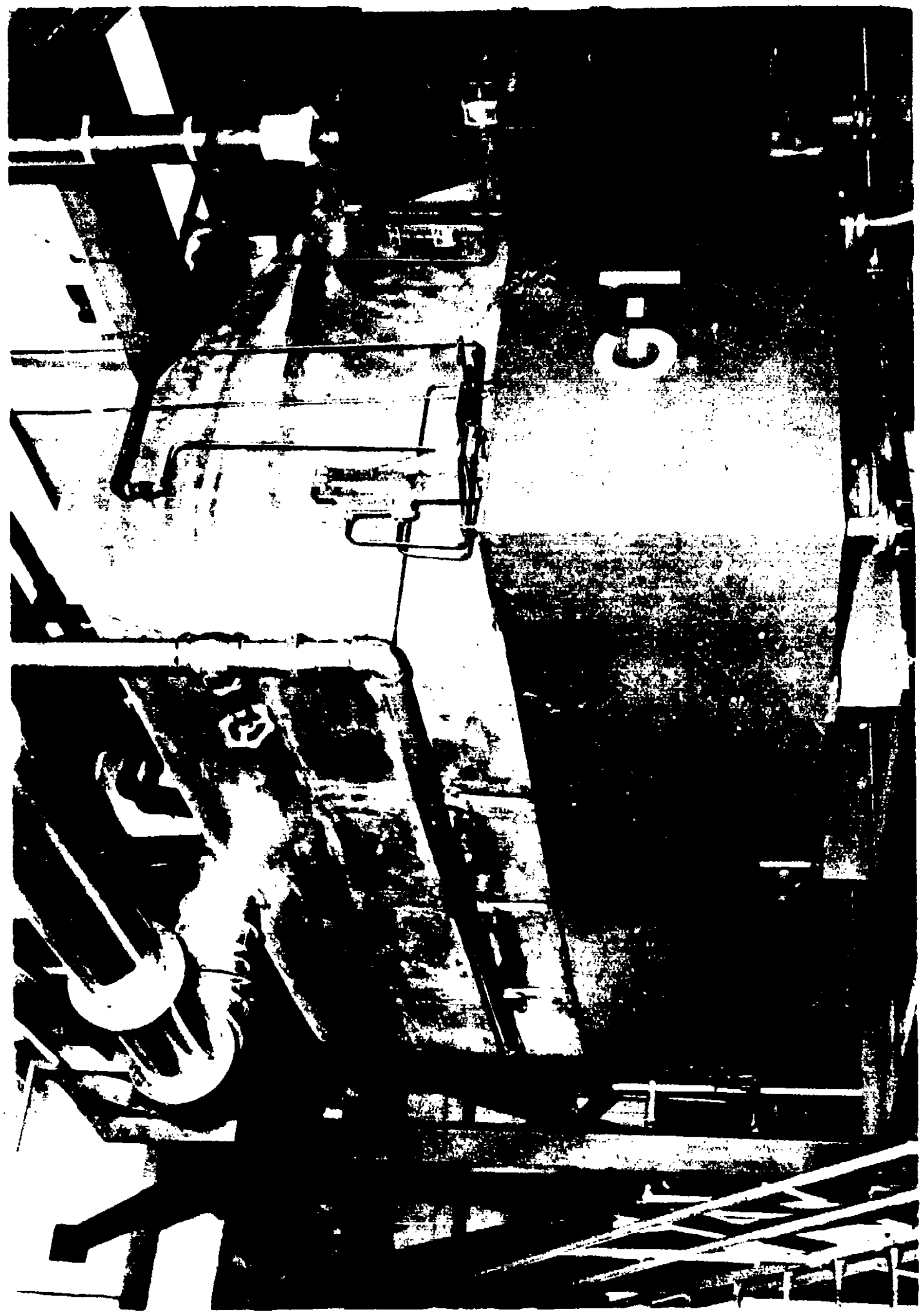


Photo #2

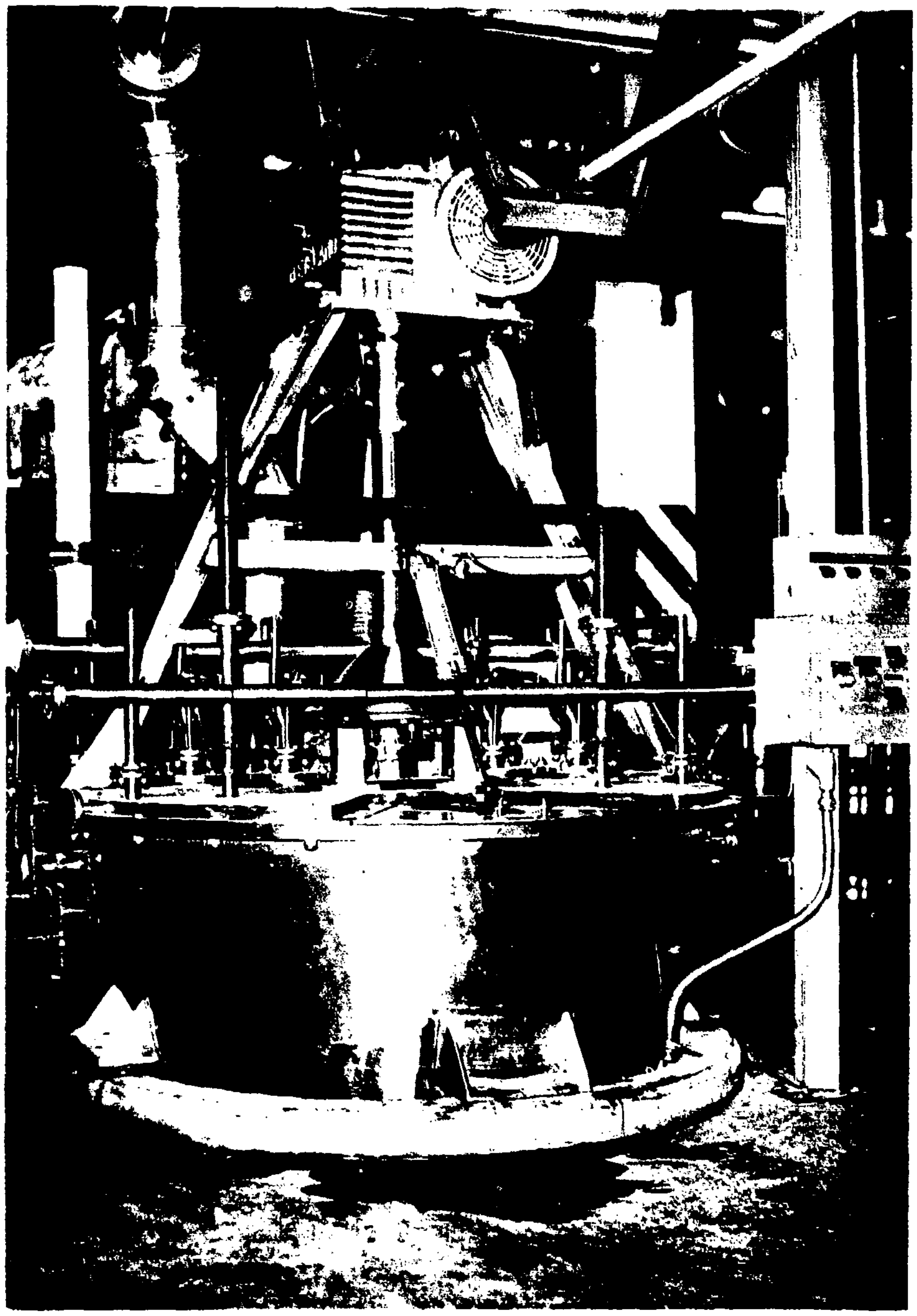


Photo #3

heated tops and bridges on these kettles to eliminate cold spots in the lids. The kettles are designed so that they will take either steam or hot water and channel the flow of either through the system in the outer jacket. An automatic air purge is installed to eliminate air locks in the heating media. An explosion proof control and indicator panel is provided at each kettle. Incorporated in this panel are the pneumatic controls and signal lights for various pieces of equipment.

Jacketed stainless steel draw off lines were chosen for use between all new equipment because of cleaning, non-sparking and non-corrosive features. These lines are designed and constructed so as to eliminate all cold spots to prevent explosives solidifications. (Photo #4)

Again, because of time and contract commitments, we were forced to use the existing holding tank, pouring manifolds and the draw off lines between them. Stainless steel equipment is on order to replace the older equipment and the same features are incorporated in the new equipment as were used in the kettles. The holding tank will have flanged inlets in the top for draw off lines connections, vacuum exhaust lines, deaeration vacuum connections, and deluge lines. The deluge lines will be equipped with spray balls so that the present Pic heating system can be tied into the sprinkler lines of the holding tank to assist in cleaning. A vacuum of 5 to 15 inches will be pulled on the holding tank to deaerate the explosive and thus to eliminate need for either vacuum kettles or vacuum pouring.

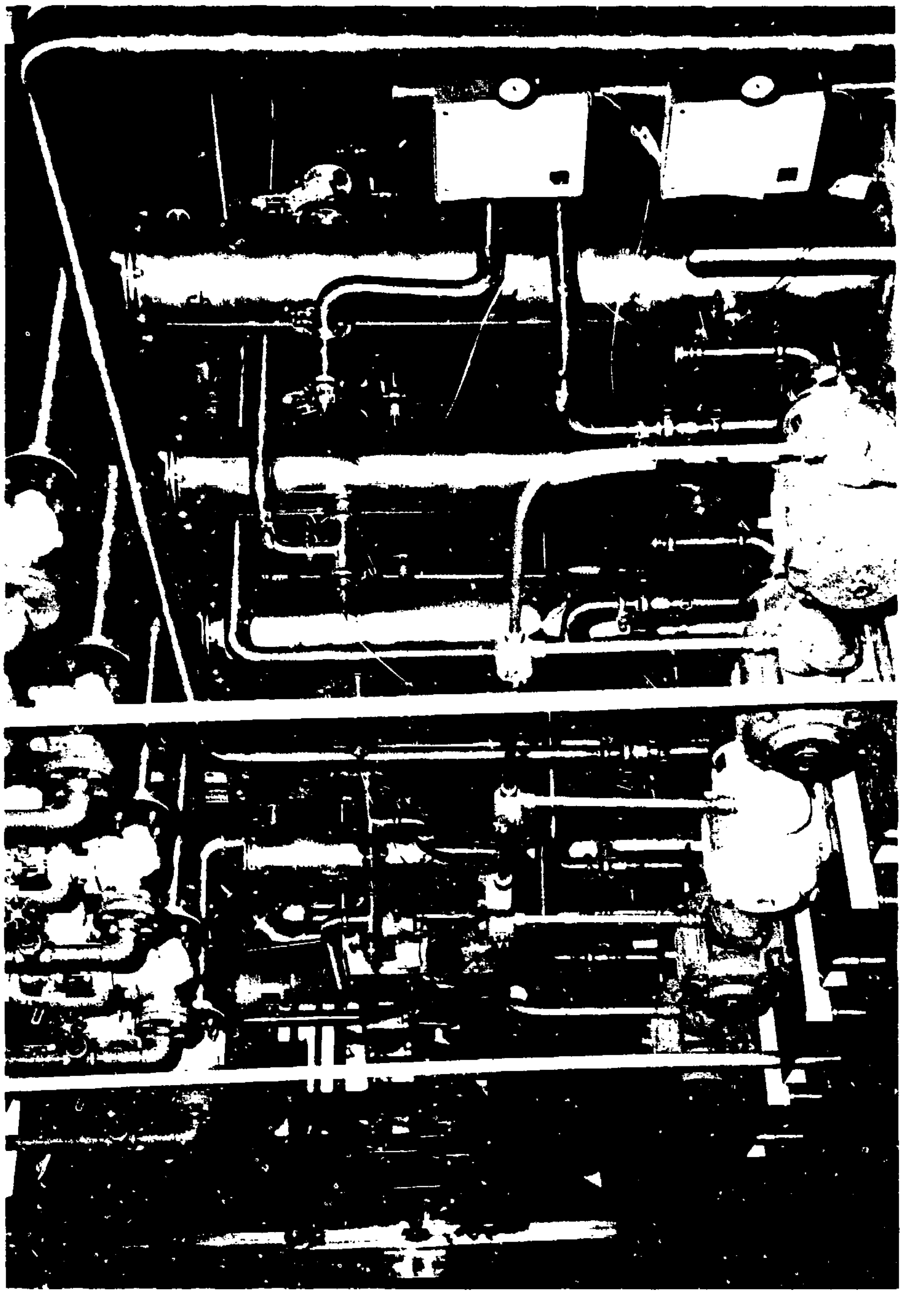


Photo #4

I briefly mentioned the control panels that are installed at each kettle. In addition to these, there is a control panel at the holding tank. Five controls are on each of the kettle panels. (Photo #5)

1. Kettle lid position, open or closed
2. Vibrating flake feed
3. Liquid explosives feed from melt grids
4. Agitator Drive
5. "Ready to drop" signal to the panel at the holding tank

The panel at the holding tank consists of six red and green lights to indicate whether the kettle contents are ready for dumping, and six pneumatic valves to operate the kettle dump valves. These dump valves are interlocked between the two panels (kettle and holding tank panels) so that the kettle operator has to throw a pneumatic switch to unblock the dump valve line. Once this is done, the holding tank operator can open the valve to dump the kettle contents. The signal lights indicate the position of the kettle dump valves.

Probably the greatest advancement in this melting operation is in the hot water temperature control system. When designing this system, primary consideration was given to simplicity of operation, operator convenience, and reduction of man-power requirements. As skilled operators became more and more scarce, a reliable, easy-to-use temperature monitoring and control system became necessary. (Photo #6)

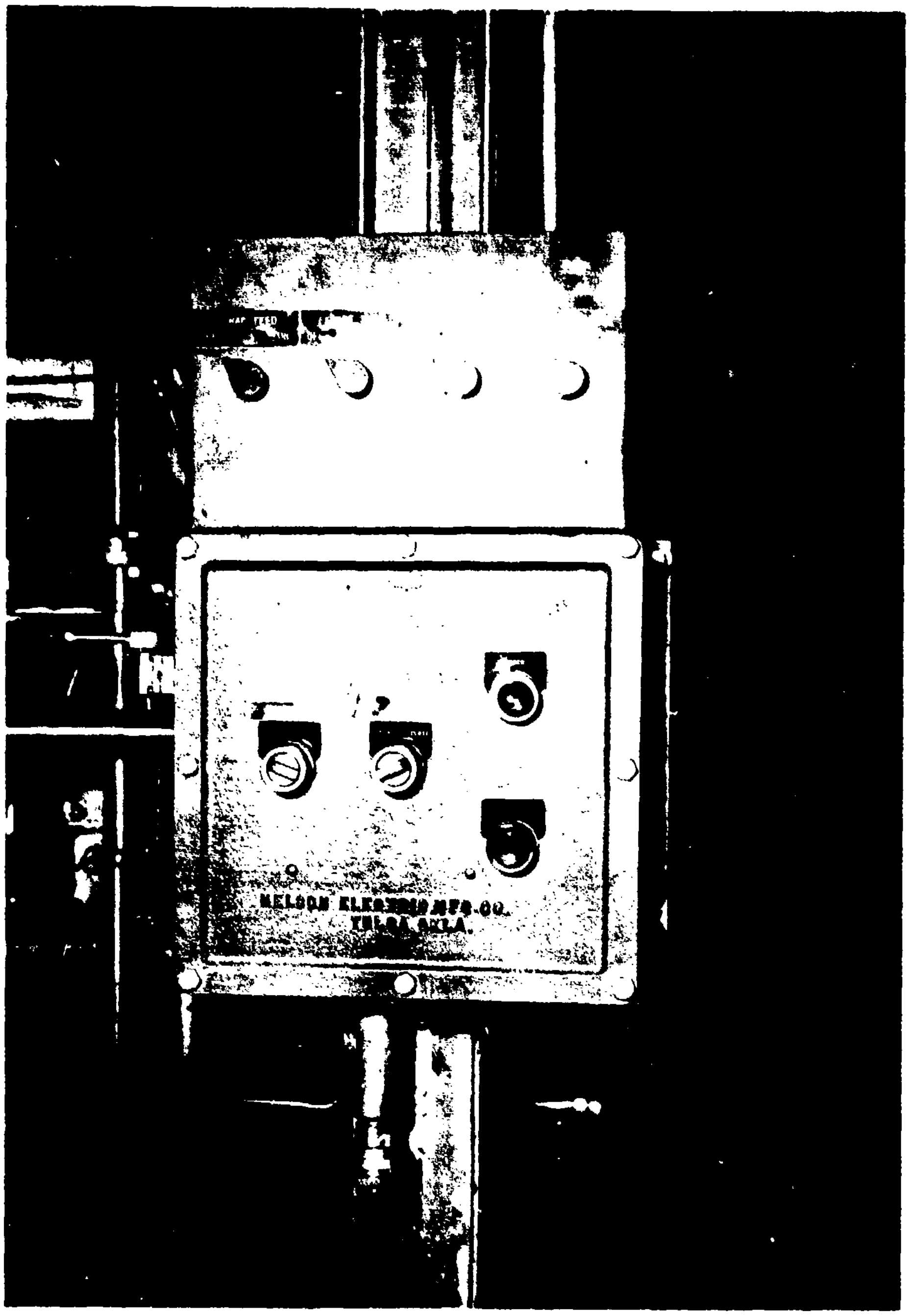


Photo #5

Photo #5

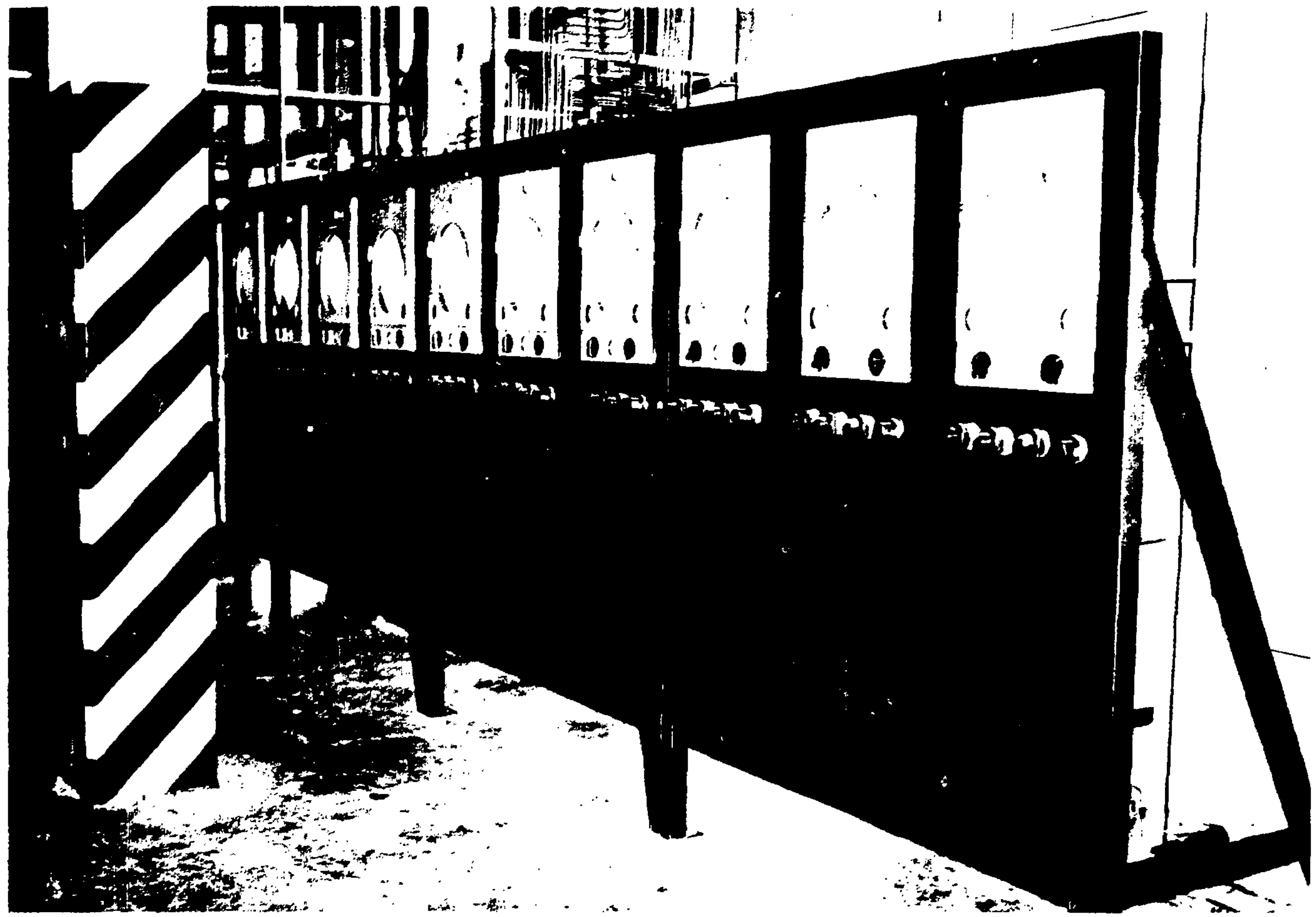


Photo #6

The system for melting the explosives, prior to this change, was strictly by steam. The steam came from the central boiler and all 6 kettles were on the same line. This, of course, meant that the temperature on all the kettles was the same. Therefore, a malfunction of a water circulating pump would adversely affect the entire system.

The new control system consists of an individual hot water set for each kettle and other melt equipment which allows for very accurate temperature control. The advantages of such a system are obvious; different explosives requiring different temperatures can be processed in individual kettles at the same time, a malfunction on the heating system of one kettle will not result in close-down of the entire operation and we are able to operate at a wide range of temperatures in the system.

A hot water set is made up of an electrical motor with pump, circulating tank, sensing units, valves, and a related control and recorder system. The same boiler and pump house, used in the previous system provides heat in the form of steam that is metered into this control system.

Basically, the control system monitors the water temperature as it is returned to the hot water set and transmits a proportional pneumatic signal to the temperature recorder-controller. This

electrical pneumatic signal is monitored for off-normal, either high or low conditions. The temperature recorder-controller, the temperature monitor, the alarm lights and horn are all mounted on a centralized control panel to provide optimum operator convenience. When the temperature on any water set goes either above or below its normal operating range, the following will occur: The operator is alerted to the off-normal condition by the pneumatic alarm horn. A light on the central control panel, which is adjacent to the equipment, indicates which system is off normal. The operator then presses the alarm silence button that silences the alarm horn for a period of 10 minutes. This gives the operator 10 minutes to switch from automatic to manual temperature control and bring the temperature back to its normal condition. If, at the end of 10 minutes, no corrective action has been taken by the operator, the alarm horn will again sound. This system not only helps to increase product quality, but gives us a controlled production procedure that can be either repeated or changed slightly, as found desirable.

We are now working on a system that will automate the complete melt pour operation. Temperature and viscosity controls will be used to regulate the melt operation. Automated conveyor systems will position the projectiles for the pouring operation.

ONE-HALF DAY SPECIALIST SESSION

"PROTECTIVE CONSTRUCTION"

Session Chairman:

Mr. G. F. Wigger

Office, Chief of Engineers

Department of the Army

Washington, D. C.

Speakers:

Mr. E. H. Buschman, Naval Ordnance Station, Indian Head, Md.

Mr. Norval Dobbs, Ammann & Whitney, New York, N. Y.

Mr. E. B. Laing, Ammann & Whitney, New York, N. Y.

Mr. R. M. Rindner, Picatinny Arsenal, Dover, N. J.

RECENT DEVELOPMENTS IN FLOORING FOR HAZARDOUS AREAS

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Naval Ordnance Station
Indian Head, Maryland

ABSTRACT

Flooring in hazardous operating and storage areas has always been a matter of concern to the explosives industry. Recently several new types of synthetic floor toppings have been introduced. These floor toppings have improved or eliminated many problem areas, such as conductivity, monolithic surfaces, compatibility, heavy traffic, and costs of installation and maintenance.

Work done by the Naval Ordnance Station, Indian Head, in their attempts to improve the flooring for hazardous areas, has discerned the advantages and disadvantages of the various toppings. It is difficult to produce a good serviceable floor that is relatively maintenance free without a comprehensive specification. Developing such a specification requires certain guidelines.

INTRODUCTION

It is a recognized fact that static electric sparks are the principal explosion hazard in arsenals, ammunition loading plants, missiles plants, and certain chemical manufacturing plants. It is also known that the only way to prevent static electric sparks is to electrically "tie" every static charge producer together to make impossible the generation of different electrical potentials. One of the primary methods of eliminating static electric sparks is through the use of conductive floors because virtually everything capable of generating static electricity comes in contact with the floor.

BACKGROUND

Conductive floors of one type or another have been in use for many years. All of these floors had certain disadvantages, some more undesirable than others. A considerable amount of research has been done to develop a good standard for determining the conductivity of floors to prevent the generation of a spark of adequate intensity to ignite a hazardous material. No universal standard has been adopted. The National Fire Protection Association (NFPA) has developed a standard used extensively in hospital operating rooms. It recommends that a conductive floor have a resistance between 25,000 and 1,000,000 ohms as measured by a 500-volt ohmmeter connected to two 5-pound weights spaced 3 feet apart at various points on the floor. This test is described in detail in their standard NFPA No. 56.

The Army, Navy, and Air Force have modified this standard to provide an adequate safety factor in the propellant and explosive fields. Generally their standard differs from the NFPA in two major aspects. First, the Army, Navy

and Air Force all allow a maximum of 1,000,000 ohms between the individual and a building ground, i. e., total resistance of conductive shoes on a person plus the resistance of the floor to the building ground. The maximum resistance of the floor must not exceed 250,000 ohms. Secondly, the floor resistance must be measured from a building ground to an electrode placed at various points on the floor. In other words, the point furthest from the building ground, as well as all intermediate points, shall not exceed 250,000 ohms.

Floors meeting this standard usually are monolithic and/or have grounding coils embedded in the floor at designated intervals. Until a few years ago the three best types of monolithic floors were lead, concrete filled with iron fillings, and oxychloride. All of these floor toppings have undesirable features.

The lead floor is very expensive to install and also expensive to maintain because it is easily damaged. It cannot meet the minimum of 25,000 ohms. On the other hand, it is compatible with and impervious to most known propellants and their ingredients. The concrete floor filled with iron filings cannot be installed to meet the requirements of an impervious floor and it is not considered a spark-resistant flooring. A third disadvantage is that it is subject to losing its conductivity because of the oxidation of the iron filings.

The oxychloride floors are produced by forming a cement by the reaction of copper particles in a gel of mineral salts and oxides. It is not impervious and it is very sensitive to humidity conditions. When the humidity is very low the conductivity of the oxychloride floor will exceed the 1,000,000-ohm maximum established by NFPA. When the humidity is high, its conductivity will be below the minimum of 25,000 ohms.

BASIC REQUIREMENTS

The basic requirements of a conductive floor will vary somewhat from one application to another. This discussion will be limited to the requirements

of an impervious and monolithic type conductive floor. This is probably the most difficult type floor to install. By modifying or eliminating some of the following requirements a floor can be installed for less severe application than that required for the impervious and monolithic floor.

(1) The standards of conductivity must be met and this requirement should never be relaxed.

(2) It must be spark-resistant or spark-proof.

(3) The floor topping and its base material should have similar coefficients of expansion.

(4) It must be strong enough to successfully withstand expected conditions of service.

(5) It must be capable of withstanding frequent washings and cleaning without impairing its effectiveness.

(6) The surface should be nondusting.

(7) The surface should be comfortable to work on.

(8) The load-carrying capacity should be adequate to prevent serious indentation by containers, wheels, etc.

(9) It must be compatible with and resistant to all chemicals and materials used in the process.

(10) It should be easily repairable without impairing its effectiveness.

(11) It should be nonabsorbent.

(12) It should be fire-resistant.

(13) It should be skid-resistant, both wet and dry.

(14) It should not soften appreciably at temperatures up to 160° F.

(15) It should withstand abrasion.

(16) The topping should have good bonding strength to the base floor.

(17) It should be resistant to common salts which may be tracked on the floor surface during the winter months and to lubricating oils and greases which may leak from equipment and lie on the floor for a considerable length of time before removal.

(18) It should be manufactured and installed by a reliable concern that will guarantee all claims.

RECENT DEVELOPMENTS

In recent years a number of companies have developed a variety of conductive floor toppings. Most of these are synthetic compounds that can be applied monolithically. Broadly these can be classified into three categories, i. e., conductive rubbers, conductive polyesters, and conductive epoxies.

Conductive rubbers are probably the oldest of these synthetics to be used as a floor topping. These were used as early as the end of World War II. These early conductive rubber toppings were not very durable but have been improved over the years. Some of the newer rubber compounds not only have good conductivity but they also hold up well from the standpoint of bonding to the base floor and wear well. However, they still lack adequate solvent resistance. At least one company is now in the position to install a thin, conductive epoxy coating on their conductive rubber. This gives a very durable and solvent-resistant floor. The rubber compounds wear well under foot and light-to-medium wheel traffic. However, they are subject to damaging indentation when used where heavy containers are handled. Compatibility with many organic nitrates also presents a problem.

The next type of synthetic floor topping developed for monolithic installation was the polyesters. This family of compounds exhibits better resistance to medium and heavy traffic. They are generally more compatible with solvents

and organic nitrates than are the rubber compounds. However, some of the polyesters have a high shrinkage rate during curing which can cause cracking of the surface when applied to large areas.

The conductive epoxy floor toppings are outstanding in resistance to identation, capability of handling heavy loads, and compatibility with solvents and organic nitrates.

The cost of installing these synthetic coatings will vary from one section of the country to another. In fact, it will vary from building to building. These variations in cost can be attributed to differences in wage scales, working conditions, type and amount of preparation required, the number of obstructions on floors, the amount of flooring laid at one time, and a variety of other factors. Generally, cost will range from about $2.00 per square foot to as much as $4.50 per square foot. The type of material used does not appreciably affect the price. The cost of synthetic conductive flooring is comparable with the conventional conductive flooring. Concrete floors filled with iron filings can be installed on new construction for $1.00 to $2.00 per square foot. If it is installed later, the cost will be from $2.50 to $4.00 per square foot. The oxychloride floor will cost $1.50 to $3.00 per square foot. Lead floors will range from $5.00 to $7.00 per square foot.

Fillers, extenders, drying powders, and aggregates are sometimes used to modify certain properties of these floor coatings. Aggregates added to the topping can produce a terrazzo-type floor, but extreme caution must be exercised so that nonsparking aggregate is used. The majority of these floor toppings acquire conductivity by the addition of acetylene black. Discretion must be exercised as excessive carbon black will impair the other qualities of the flooring.

These toppings are generally not difficult to apply if the base floor is in good condition and has been properly prepared. Care must be exercised in using the proper proportions of each ingredient, mixing in the prescribed manner, and

applying as directed within the specified time after mixing. If there are any deviations from the above precautions, it is possible that a nonconductive surface will be the result. This actually happened with one company that submitted an evaluation sample to Indian Head.

SPECIFICATION GUIDELINES

To ensure a good floor it is imperative that a comprehensive specification be used. This specification should include the physical and chemical characteristics of the topping, as well as the preparation of the base floor and the method of application of the topping itself. Let us consider some of the salient points in developing a comprehensive conductive flooring specification. (These guidelines are not to be construed as a specification but merely some of the major points used in developing a specification at Indian Head.)

Conductivity:

This should include both the upper and lower resistance limits as well as the procedure for measuring this resistance. At Indian Head we are using 250,000 ohms as the upper resistance limit for the flooring and 0 ohms as the lower limit. The purpose of the lower limit is to prevent severe shock if an operator comes in contact with an electrical power source. To preclude this, we have built the 25,000-ohm lower limit into our shoe specification. We also have had some experience with synthetic toppings in which the resistance increases appreciably after the topping cures in 4 to 6 months. Imposing a 25,000-ohm minimum on the flooring contractor can cause the final cured topping to exceed 250,000 ohms, therefore, our lower limit is 0 ohms. The method of measuring this resistance can be found in various military documents or you can refer to the method used by NFPA in their Standard No. 56 and substitute an alligator clip for one of the electrodes. Readings are then taken by attaching the clip to the building ground and placing the other electrode at various locations

on the floor including the points furthest from the building ground. The conductivity readings should be taken at least three times before final acceptance. The first reading should be taken at least 5 days after initial installation and repeated at the end of 6 months and 12 months. Additional readings may be justified if the conductivity is close to the maximum allowed.

So far we have been discussing only surface resistivity. A durable floor that will maintain its conductivity throughout its lifetime must also exhibit good volume resistivity. The volume resistivity can be determined by ASTM D-257. This volume resistivity should not exceed 5,000 ohm-centimeters.

Eliminating Cracks and Voids:

Since we work primarily with impervious floors at Indian Head, our specifications include a section on eliminating cracks, voids, etc. We require a seamless, monolithic, integral, sanitary cove base formed at the same time that the floor is laid. This cove base should also be extended up on all floor protrusions, such as pipe sleeves, conduits, and equipment bases. The floor topping should be free of joints, crevices, or other apertures in which powders or liquids can accumulate and the top edge should have a smooth feathered edge. It is advisable to reinforce all areas of stress with a minimum of 10-oz woven roving fiberglass. Some companies prefer to reinforce the entire floor with fiberglass.

Base Floor Preparation:

The base floor preparation for conductive topping is of utmost importance. If the floor topping is not properly installed and bonded it will not last very long and its conductivity may be impaired particularly if grounding coils are used in the floor. The base floor must be clean and free of depressions, protrusions, and blemishes. If concrete is used as the base it should have a good wood float finish, followed by sufficient steel trowelling to effect a finish like that required for resilient flooring. Concrete floors can be cleaned with a solution of tri-sodium

phosphate or hydrochloric acid, neutralized, and rinsed. Surface-applied curing agents should not be used as they might affect bonding to the base floor. Bonding strength can be specified to conform to ASTM C321 "Method of Test for Bond Strength of Chemical-Resistant Mortars." It must have a minimum of 250-psi bond strength as determined by this test.

Wood floors, when used as a base for conductive topping, must be sound and solid. They should first be prepared by installing 15-pound perforated asbestos felt and overlaying it with 2.5-inch wire both secured on 5-inch centers with strong staples.

Fire Resistance:

Another important consideration in every hazardous operation is fire resistance. Conductive floor toppings are no exception to this. The contractor should certify that the installed material is classified as maximum rate 0.5 inch per minute when tested in accordance with ASTM D635, "Method of Test for Flammability of Rigid Plastic Over 0.127 cm (0.050 inch) in Thickness."

Compressive Strength:

To determine how well the floor will endure hard usage, the compressive strength should be measured. The compressive strength can be determined by ASTM C306. The floor must withstand a compressive load of 2,500 psi minimum without failure.

Impact Resistance:

Resistance to impact should not exceed an 0.033-inch depth with no sign of chipping, cracking, or detachment from backing when tested as follows: Samples are mounted on a steel plate, held on a solid horizontal base, and subjected to the impact of a 2-pound steel ball dropped vertically from a height of 8 feet so that the impact will be at the center of the sample. Each sample is subjected to two impacts of the steel ball.

Indentation Resistance:

Indentation resistance must not exceed 3% of the thickness of the topping when tested as follows: Samples mounted on steel plates are subjected to a compression test using a steel ram with a 1-1/8-inch-diameter flat face resting on the center of the sample with a force of 2,000 pounds for 1 hour. This test shall be performed on two sets of samples, the first set to be conditioned for a minimum of 24 hours at 70° ± 5° F, the second for a minimum of 24 hours at 160° ± 5° F.

Slipperiness:

Slipperiness can be a problem with some of the newer type floors because many of them are applied with a trowel. The slipperiness can be controlled to some extent by the way the floor topping is finished. It can be improved by taking a paint roller with the proper type nap, wetting it with an appropriate solvent, and rolling it lightly over the uncured topping. The floor finish should be nonslip, both wet and dry, with the following features being minimum requirements:

	Static Friction			Sliding Friction		
	Dry	Wet	Oily	Dry	Wet	Oily
Leather	1.00	1.00	-	0.40	0.65	-
Rubber	0.60	0.70	0.40	0.40	0.70	0.30

The resistance to impact, indentation, and slipperiness are detailed in MIL-D-3134F. If desirable, other aspects of this specification may be used to specify moisture absorption, resistance to elevated temperatures, and resistance to salt corrosion.

Organic Nitrate Absorption:

At Indian Head we are particularly concerned about absorption of organic nitrates. Since there is no published standard test, we developed our own. We

begin by building a dam on top of the sample flooring. This dam is filled with a 75% solution of an organic nitrate which is allowed to set for 48 hours. The organic solution is removed and the flooring sample is rinsed twice with acetone. Surface chips are taken from the area exposed to the organic solution. The chips are immersed in a methylene chloride-acetone solution (1:1 mixture). The liquid is then spot tested for nitrates by the sulfanilic acid-zinc reduction method. A blank sample should also be run with floor chips taken from an area not exposed to the organic solution.

Solvent Resistance:

The supplier must certify that his floor topping has good resistance to all the conventional solvents used in that part of the plant, as well as any other chemicals that might be spilled on the floor. The test should be made by having a flooring sample in constant contact with the chemical for a minimum of 7 days. After such exposure the sample should not have softened, blistered, cracked, peeled, or dissolved.

Shrinkage:

It is advisable to incorporate a shrinkage requirement because certain synthetics are subject to excessive shrinkage. Linear shrinkage up to 0.10% on an unmounted floor topping sample is not objectionable. The supplier should certify that his material will not crack, pull loose at the edges, or weaken its bond to the base floor because of shrinkage. He should be willing to back up this warranty with installations in which his floor topping has been used for at least 2 years.

Abrasion Resistance:

Another test for determining the durability of a floor is the abrasion resistance test. There is no ideal standard for measuring abrasion resistance. The ASTM C-501 standard is one that is frequently used. It employs a Taber

machine with a CS-17 wheel with 1,000 grams of weight operated for 1,000 cycles. The calculated abrasion value should not be less than 25 and the specimen should meet all conductivity requirements after the test is completed.

CONCLUSIONS

The floor toppings currently available are no panacea for every problem. On the other hand, the conductive flooring industry has made and will continue to make many worthwhile contributions to the chemical industry. These contributions have helped immeasurably in decreasing incidents caused by generation of static electric sparks.

The major points to consider in developing a specification for synthetic conductive flooring have been discussed. As mentioned, not every requirement will be needed for every installation. Other guides will have to be developed as the synthetic materials are improved and new ones become available. There are many qualifications a conductive flooring must meet. The performance and safety of floorings should be measured by various tests designed for each problem area.

COST EFFECTIVENESS STUDIES OF

FACILITIES FOR HIGH-HAZARD EXPLOSIVE MATERIEL

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ABSTRACT

To reduce the construction cost of explosive facilities employing new design techniques a cost reduction program has been developed. Described are some of the studies and tests which have or will be conducted. In addition to discussions of proper siting and selection of concrete sections to achieve economy in construction, experiments to investigate the feasibility of using new materials to establish new structural configurations which will be advantageous for safe storage and manufacturing of hazardous materiel are described.

COST EFFECTIVENESS STUDIES OF FACILITIES FOR HIGH-HAZARD EXPLOSIVE MATERIEL

INTRODUCTION

Criteria and methods based upon results of catastrophic events have been used for the design of high explosive storage and manufacturing facilities. These criteria and methods did not include a detailed or reliable quantitative basis for assessing the degree of protection afforded by the protected facility, and therefore extensive research and development programs have been undertaken to establish procedures which are adequate for current and future design requirements.

Recent tests of new types of blast-resistant structures have demonstrated that, when properly designed and detailed, reinforced concrete and other materials may be used effectively to prevent propagation of explosions and to provide protection for personnel and valuable equipment.

These new protective structures use higher percentages of reinforcement and more concrete than the "Standard Substantial Dividing Walls" previously used for blast protection. While the construction costs per square foot for the new designs are higher, the cost per unit weight of stored explosive is substantially less for the same degree of protection. Furthermore, use of these new designs allows siting and orientation adjustments which can result in more efficient operations and reduced costs for buildings, land, utilities, roads and ancillary facilities.

The design techniques, cost data and test programs reported here have been developed by Ammann & Whitney under Contracts DAAA-21-67-C-0127 and 0941 to Picatinny Arsenal as part of their Supporting Studies Program for The Armed Services Explosives Safety Board.

Structure Response

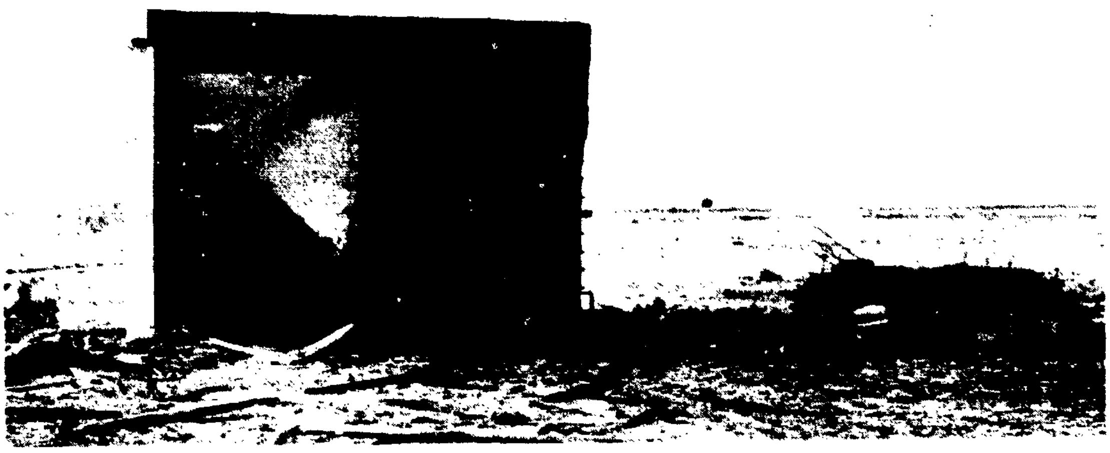
Tests have been conducted of reinforced concrete full-scale and model cubicles and other conventionally designed structural elements housing explosives. These tests, conducted at the U.S. Naval Ordnance Test Station (NOTS) and other military installations, have demonstrated the limitations of such designs in preventing propagation or providing protection close to detonations. It was observed, that with the patterns and amount of reinforcing steel used in the usual "12 inch Substantial Dividing Walls" (Fig. 1, Ref. 1), the potential ductility (ability to deform) of the members was not developed sufficiently to permit attainment of required ultimate blast resistant capacities. As a result of the limited deflections, inadequate energy absorption occurred prior to failure. Moreover, a major portion of the resulting rubble was small indicating spalling of the concrete cover over the reinforcement and fragmentation of the concrete between the tension and compression layers of the reinforcing steel. This internal fragmentation of the concrete contributed to the reduced ductility and eventual collapse.

To increase the blast resistant capacity of concrete structures above that afforded by the "Standard Dividing Walls", a research program has been conducted under which new techniques have been devised for the design and construction of reinforced concrete structures. These new techniques enable the structures to develop the extremely large deflections required to prevent structural failure. Model and full-scale tests of structures designed by these techniques have been successfully performed with the result that, even when failure was permitted, fragment velocities were substantially reduced and danger of propagation minimized.

For maximum ductility of a member, relatively large bending strains must be developed. To achieve a ductile response, sufficient amounts of properly detailed reinforcement must be provided so that the ultimate blast-load capacity is realized. Adequate strength to resist the high shear stresses, occurring near supports and at interiors of spans,

Ref. I

PRE-SHOT VIEW



POST-SHOT VIEW

FIGURE I

must also be provided.

To assure ductile action, to develop the full flexural strength and to reduce velocities and number of concrete fragments after failure, radical changes were required in reinforcement design (Ref. 2). The straight flexural steel was substantially increased in quantity above that previously used. In addition, the flexural reinforcement was laced together with well anchored, continuous bent diagonal bars (Fig. 2).

The action of the laced reinforcement contributes to the integrity of the protective structure in several ways:

1. Ductility of the flexural steel, including the strain hardening region, is fully developed.

2. Integrity of the concrete within structural members is maintained despite massive crushing.

3. Compressive reinforcement is restrained from buckling.

4. High shear stresses at the supports are resisted.

5. Local shear failure, produced by the high intensity of the peak reflected pressures, is prevented.

6. Quantity and velocity of fragments are reduced.

Lacing Mechanism

The resistance-deflection curve (Fig. 3) illustrates the ability of lacing reinforcement to develop flexural strength. By preventing premature failure, the lacing enables a concrete element to deflect until tension failure of the steel occurs. At this point, the strain hardening region (that portion of the stress-strain curve beyond the yield point where strength increases with continued yield) of the steel is fully developed. With the reinforcement used in "Standard Walls", cracking and dislodgement of the concrete between reinforcement layers and buckling of compression steel produce failure of the element long before the ultimate strain of the reinforce-

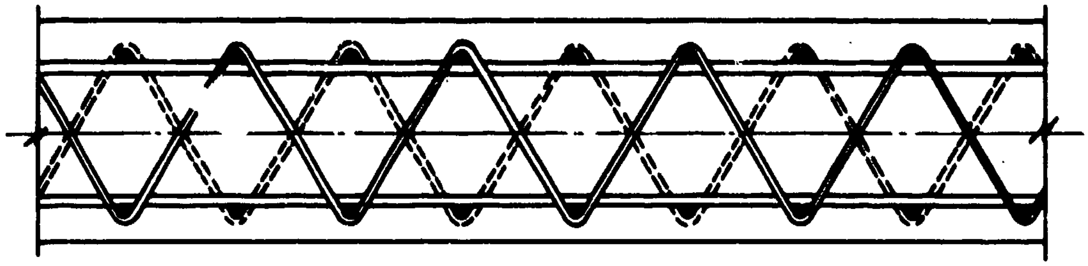


FIGURE 2
LACED REINFORCEMENT

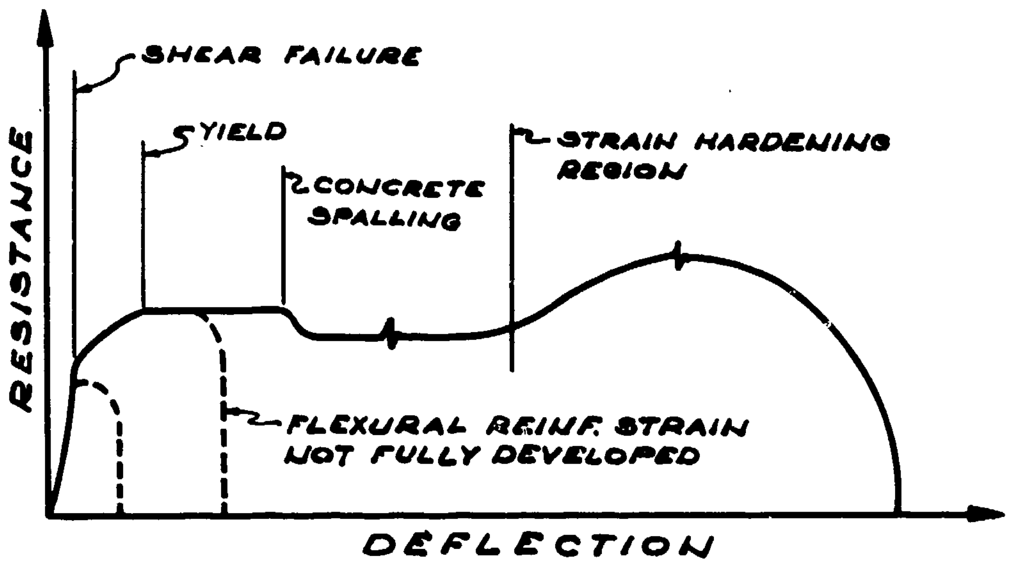


FIGURE 3
RESISTANCE - DEFLECTION CURVE

ment is achieved.

With laced reinforcement some reduction in strength occurs because of crushing or spalling of concrete in the compression region. However, the concrete simply fails and compression stresses are transferred to the steel reinforcement without failure of the member.

Lacing also provides strength for resisting high shear stresses near supports. This required capacity is developed by the strength of the lacing and by enabling full development of both the dowel action of the flexural steel and the remaining strength of the concrete. Moreover, because of the continuity of the lacing, local shear failures caused by the non-uniformity of the applied impulse loads at interior portions of concrete elements are obviated.

Properties of Laced Walls

Figure 4 illustrates typical reinforcement details for two types of laced concrete walls, namely: (1) single walls and (2) composite walls open at the top.

For a single wall which is free to move at the top and is supported at its sides and by the floor slab, and for a cantilever wall where the support is usually provided only by the base slab, the vertical lacing is placed continuous from approximately the mid-height of the wall (above the floor or haunch) to the bottom of the wall.

In the upper half of the wall, the horizontal lacing reinforcement is continuous over the full length of the wall and anchored in the side supports. In the case of the cantilever wall the horizontal lacing distributes the high local shear stresses adjacent to the explosion to other sections of the wall where the blast load intensities are of smaller magnitude.

The main flexural reinforcement of laced walls is placed interior of the lacing with the straight steel being symmetrical at both the compression and tension surfaces of the wall. In the lower half of the wall the horizontal steel is placed exterior of the vertical bars whereas in the upper

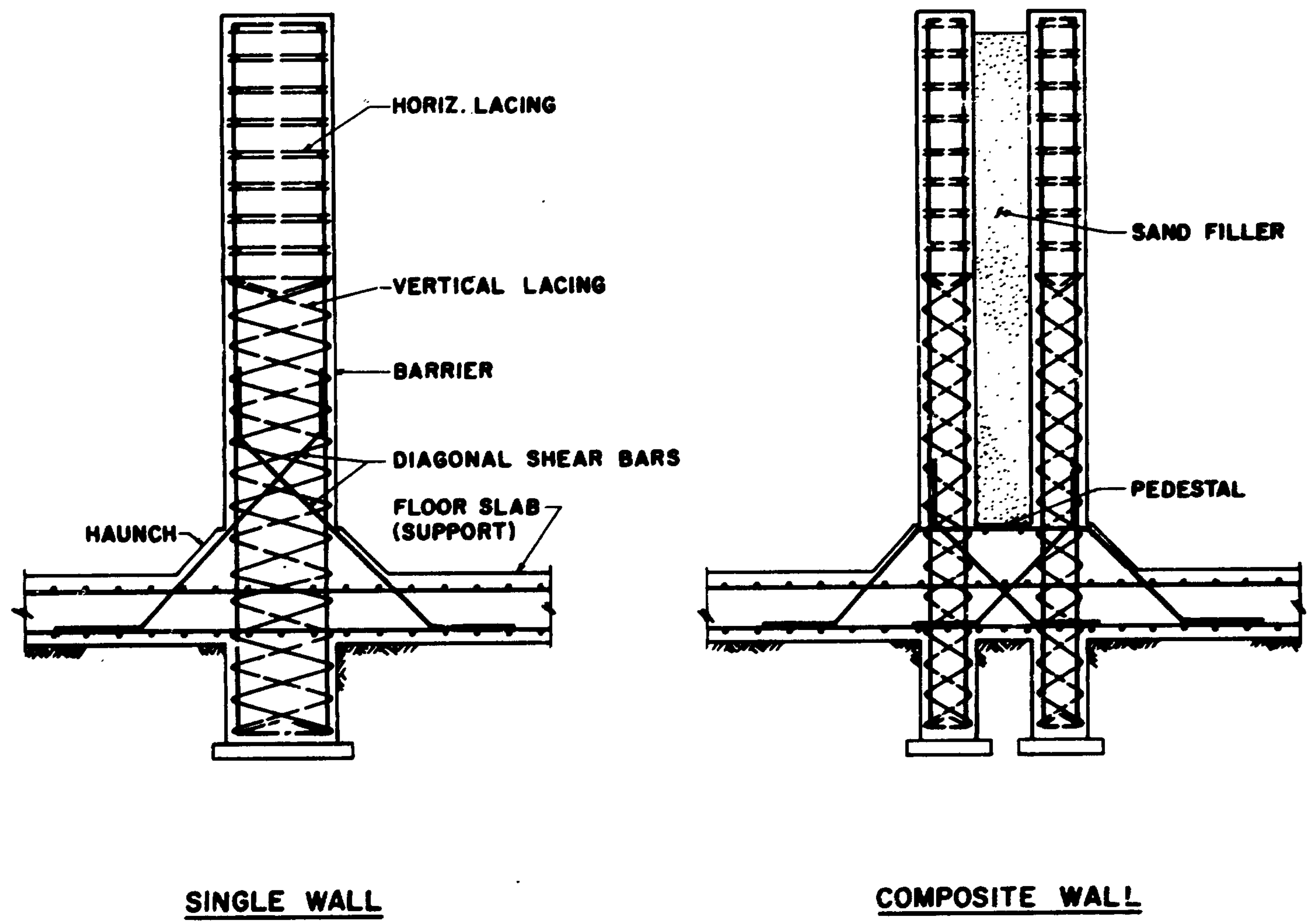


FIGURE 4
TYPICAL LACED WALL DETAILS

half the horizontal steel is interior of the vertical bars. To reduce the size of spalled fragments resulting from the displacement of the concrete cover over the steel, the thickness of the wall may be reduced such that the same concrete cover is maintained at both upper and lower sections of the wall.

A portion of the single wall should extend below the bottom of the floor slab. This extension provides the required anchorage for both the flexural steel and lacing. In the case of a single cell cubicle, this lower extension of the wall (or lip) will assist in resisting sliding and overturning of the overall structure. In those cases where adequate resistance is not afforded by the soil, the lip and the portion of floor slab below the wall will provide the necessary space for placement of reinforcement to resist the vertical bending in the wall induced by the blast loads acting on the floor slab adjacent to the wall.

The second type of laced wall construction consists of two reinforced concrete panels separated by sand. Details of each concrete panel are similar to those described for the single walls. However, a tie system at the base of the panels is required to form a monolithic support. Tie reinforcement is continuous across the base of both panels and a separating concrete pedestal. This steel terminates in the floor slab.

Although sand has been the only filler material used in recent tests of composite walls, a new test program is presently in progress to determine if cost reductions can be achieved with the use of composite construction utilizing other energy absorbing materials.

COST EFFECTIVENESS

The relationships between the three components (donor and acceptor systems and protective barrier) of an explosive facility can be defined for the purpose of achieving economy and safe design (Fig. 5). Initially, the donor system is analyzed and the explosive output, in terms of primary missiles and blast pressures, is determined. An appropriate protective structure (shelter or barrier) is then selected to afford the required protection for the acceptor system

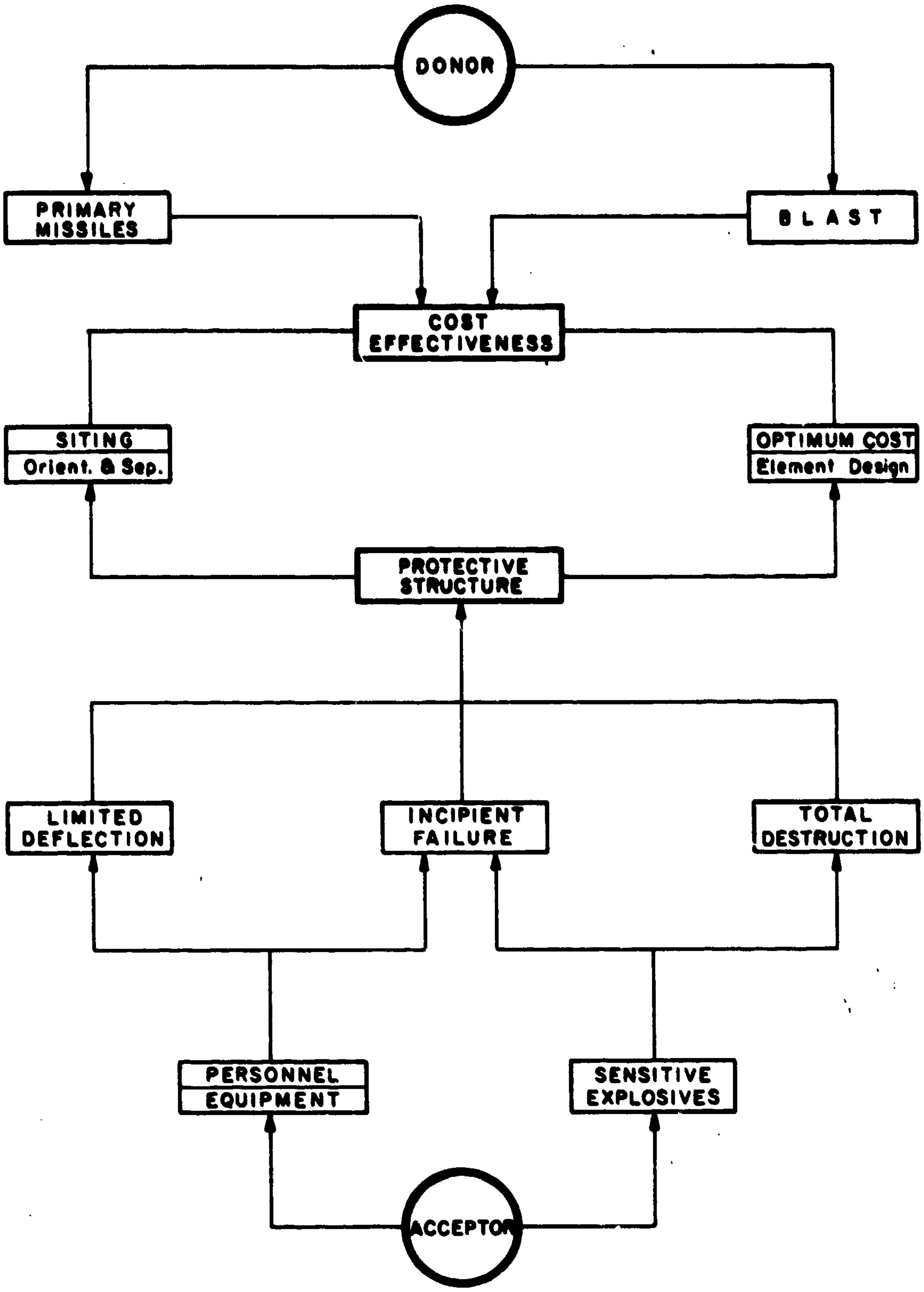


FIGURE 5
COST EFFECTIVENESS SYSTEM

(personnel, equipment or another explosive).

Once the loading and the structural configurations are determined, proper siting (orientation and spacing) of the structure is accomplished to achieve maximum cost effectiveness of the overall facility. After the structures have been located, the individual structural elements are designed. The required bending resistances, mass and deflections are computed for the predetermined response range of the structure. This response range is a function of the necessary type of protection desired, i.e., (1) limited deflections, usually used in shelter design for personnel protection, (2) incipient failure where either personnel or other explosives require protection close to the detonation or (3) total destruction with limited fragment velocities or trajectories.

The overall configuration and response of the elements will be predicated by the operational functions of the facility and safety desired. The type of barrier (plain or composite construction, support conditions, etc.) will be governed by economy.

Site Planning

Because of the wide variation in operational requirements, cost effectiveness of proper siting will usually be specific to each facility. However, certain guide lines may be established which will reduce construction costs in new facility designs.

Economy by siting of facilities may be achieved by minimizing distances between and proper orientation of on-site structures. Required separation distances will usually be governed by the blast effects of the detonation whereas both missiles and blast will be factors in determining structure orientation.

Until recently, the quantity-distance tables (Ref. 3) were used exclusively to establish separation distances between potential hazards and protective structures. Although these tables did specify distances which correspond to safe overpressure levels for all charge weights, no quantitative assessment of the blast impulse or structure response is

included in their application.

New facility designs which consider both pressure and impulse for establishing safe distances will produce economy not only in land reduction but also by cost savings realized from the reduction of required length of roads, security fences and other auxiliary apparatus (tramways, walkways, piping, wiring, etc.) which interconnect the various on-site buildings and off-site areas. In the case of reinforced concrete protective shelters for personnel, the required separation distances calculated using both blast parameters (pressure and impulse) and the structural response may be greatly reduced from those specified in the quantity-distance tables.

Another factor which can significantly affect required separation distances is the possibility of the occurrence of simultaneous detonations. If a protective structure containing several potential explosions is designed to prevent propagation of explosions from one area to another, then structures located adjacent to the building containing the potential hazard can be sited based on separation distances to provide safety from a single detonation. Laced reinforced concrete dividing walls can be designed to prevent propogation. On the other hand, where propagation("simultaneous" detonation) occurs, safe distances between buildings must be substantially larger. The magnitude of this increased distance is dependent on the number and size of the potential explosions.

Structures containing explosives should be oriented to minimize damage to the remainder of the facility and off-site areas. Barriers, cubicles and igloos are generally oriented such that the frangible portions of the structure will direct the blast and missiles away from other site structures and in the direction of minimum off-site population and facilities. Vertical silos and other structures flush with the ground surface would have the frangible cover facing upward (Fig. 6). Direction of the debris from the frangible portions of these structures can often be controlled by proper detailing.

In the case of the earth-mounded igloos, the entrance-

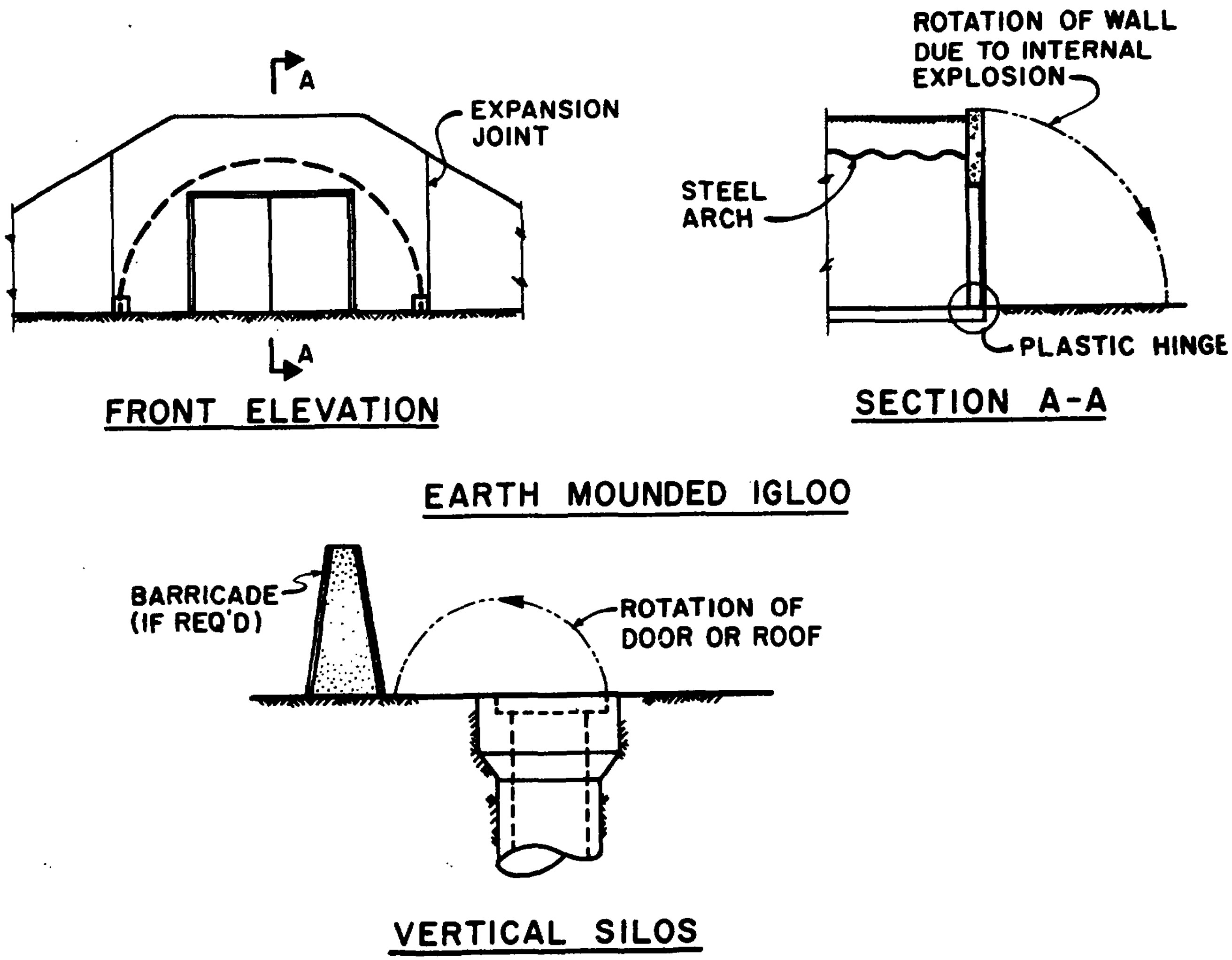


FIGURE 6
CONTROL OF DEBRIS

way portions (steel doors and concrete retaining wall) usually form the major debris hazard to other structures. Use of laced reinforcement in the retaining walls and strengthening of door hinges will appreciably reduce the travel of the debris and in many cases prevent disengagement entirely (Fig. 6).

On the other hand, a protective structure not housing explosive hazards should be oriented to minimize the effects of the blast output on its exterior surfaces and within the structure itself. Minimum cost is attained when the smallest exposed wall area of the building faces the hazard, thus reducing the overall blast load acting on the structure. Of particular importance in this regard is blast load caused by the reflected pressures acting on the surface facing the detonation, where amplification of the shock pressures occurs when the pressure front impinges on the structure.

When explosions occur in cubicle-type structures, the blast pressures propagating from the open end of the structure will be higher, at a given distance, than those pressures acting on the ground surface adjacent to the cubicle walls (Fig. 7). Therefore, economy will be achieved by siting other facility structures (containing explosives or personnel) opposite the cubicle walls with the open end of the donor cell directed towards off-site remote areas.

The number and size of openings in shelters should be held to a minimum, and, if possible, they should be windowless. When required for operational purposes, openings in shelter structures should be placed in those surfaces facing away from the potential explosion. Depending on the size of the structure, the savings by eliminating windows will offset the costs of ventilation or air conditioning when required.

Quite often windowless buildings may be located closer to potential explosive hazards than conventional structures with earth barricades. In these cases, cost savings achieved by the elimination of the barricades and by the land reduction will offset the increased building cost. Furthermore, reduced operational costs will usually be realized.

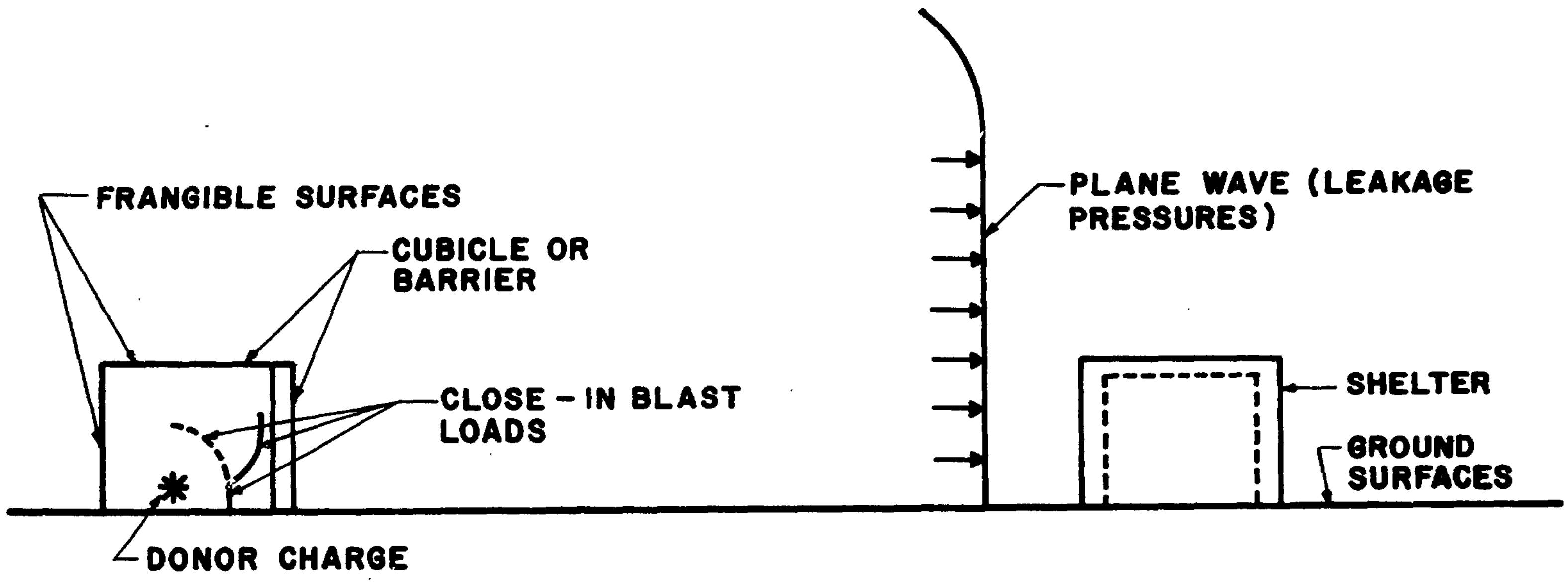


FIGURE 7

BLAST PRESSURES FROM EXPLOSIONS IN CUBICLE STRUCTURES

Although locations of site roads and walkways usually cannot conform to minimum distances required for conventional operations, they should be oriented with consideration for maximum protection and the factors involved in recovery from accidental explosions. Earth-mounded barricades and/or revetments (earth mounds with wood or sheet piling retaining walls) for debris protection may be useful to achieve economy in road construction.

To achieve an economical design, the orientation must be balanced against the operational needs of a particular building and its relationships to other off-and on-site structures with particular attention to those buildings housing the maximum potential hazard.

Optimum Structural Cost

Once the arrangement of the protective structure has been selected, individual elements (wall, floor and roof slabs) may be designed to provide the protection required. The degree of protection referred to previously (limited deflection, incipient failure or total destruction) and the thickness required for walls are significant factors in determining the structure's cost effectiveness.

As an example, consider a cantilever dividing wall similar to those described in Ref. 4. Each wall has an overall height of 15 ft. with a 1 ft. by 1 ft. haunch located at the base slab. The length of each wall is 3 times its height, The walls were designed to resist the blast output from a maximum charge weight of 7,500 pounds H.E. located 12 ft.-6 in. from their surfaces. The design height of the charge above the floor slab is equal to one-quarter the wall height.

Results of cost analyses, considering the use of laced reinforcement and based on incipient failure criteria, indicate that for a potential explosion equal to or greater than 110 pounds the minimum cost (per square foot of wall surface excluding formwork) will vary as a power function of the charge weight (Fig. 8). This power function is dependent upon the relationship between the unit prices of the reinforcement and concrete.

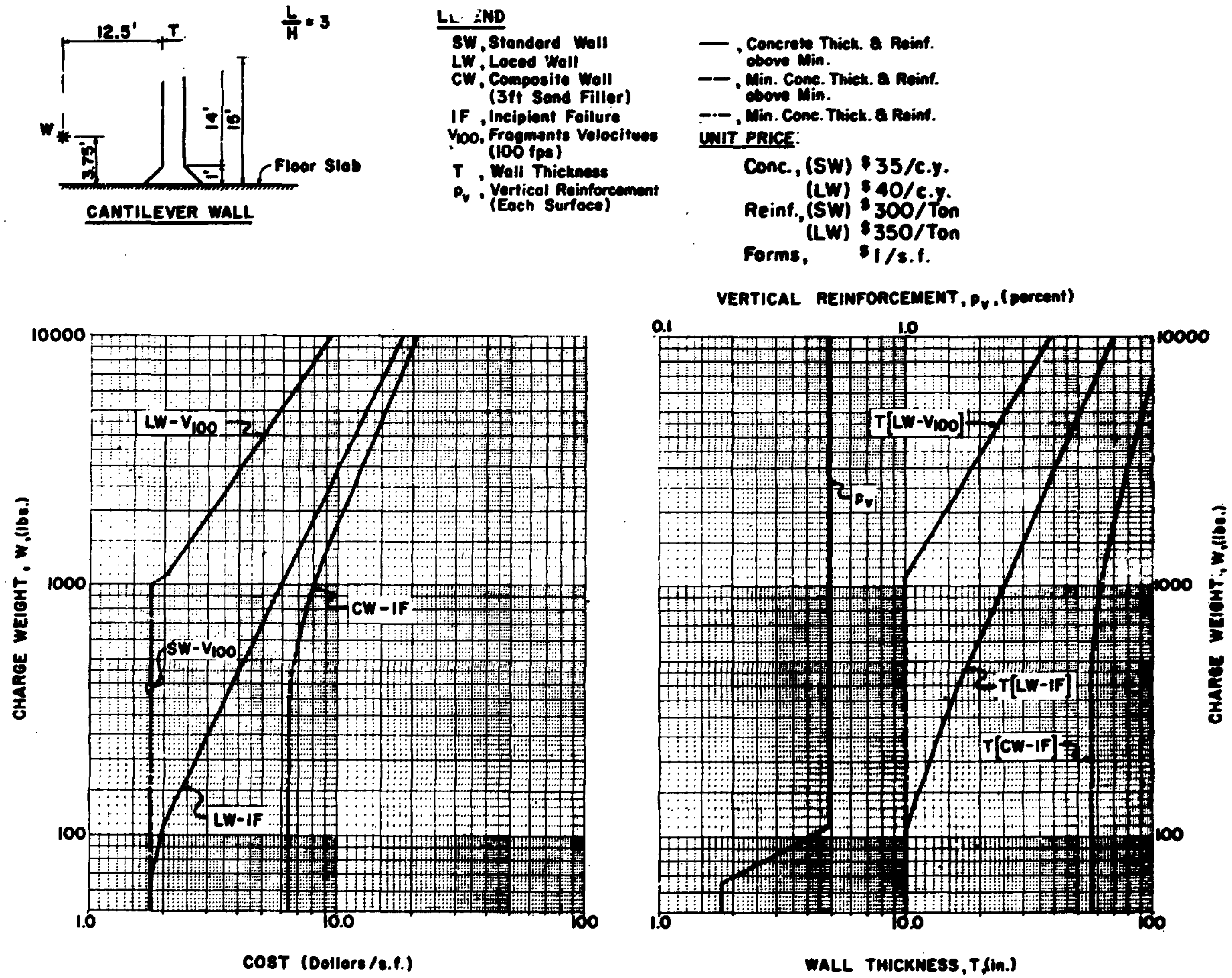


FIGURE 8

COST ANALYSIS OF LACED CANTILEVER WALL

For the unit prices ($350/ton for steel and $40/cu yd for concrete) considered, it is shown (Fig. 8) that the cost of the wall to resist a 1000 pound explosion would be $79 per cubic yard of concrete (including formwork) which is in the order of magnitude of conventional concrete structure costs (Ref. 5).

The analysis also indicated that, to obtain minimum construction cost, the thickness of the wall should be increased as the charge weight is increased. This concrete thickness should be compatible with flexural reinforcement (vertical steel in each surface of a cantilever wall) equal to 0.49% (optimum reinforcing steel). Although this optimum reinforcement will vary with the cost of materials, this variation will be small. For example, when the concrete price varies between 35 and 45 dollars per cubic yard and the steel price varies from 200 to 500 dollars per ton, the upper and lower limits of the optimum reinforcement will be approximately 0.65 and 0.4 percent, respectively (Fig. 9). This variation will not significantly affect the power function variation, charge weight versus cost, as given in Fig. 8.

The lower limit of the charge weight (110 pounds) in the power function relationship is dependent on the minimum thickness of concrete walls as specified in Ref. 6. Another power function of the charge weight versus construction cost will occur at charge weights less than 110 pounds. This relationship is controlled by the variation of reinforcement from the optimum to that specified for minimum steel (0.18% for A432 reinforcing bars, Ref. 6). The cost will be constant for all charge weights less than that which can be resisted by the minimum section.

For comparison, the costs of laced single walls designed to approach incipient failure conditions were compared with costs of composite walls (two laced concrete panels separated by 3 feet of sand) designed for the same protection, and also compared with costs of laced single walls, designed to fail with controlled fragment velocities of 100 fps or less. For the range of charge weights considered, composite construction using sand as the filler material would be more expensive. Furthermore larger overall wall sections are required. However, at very large charge weights both cost

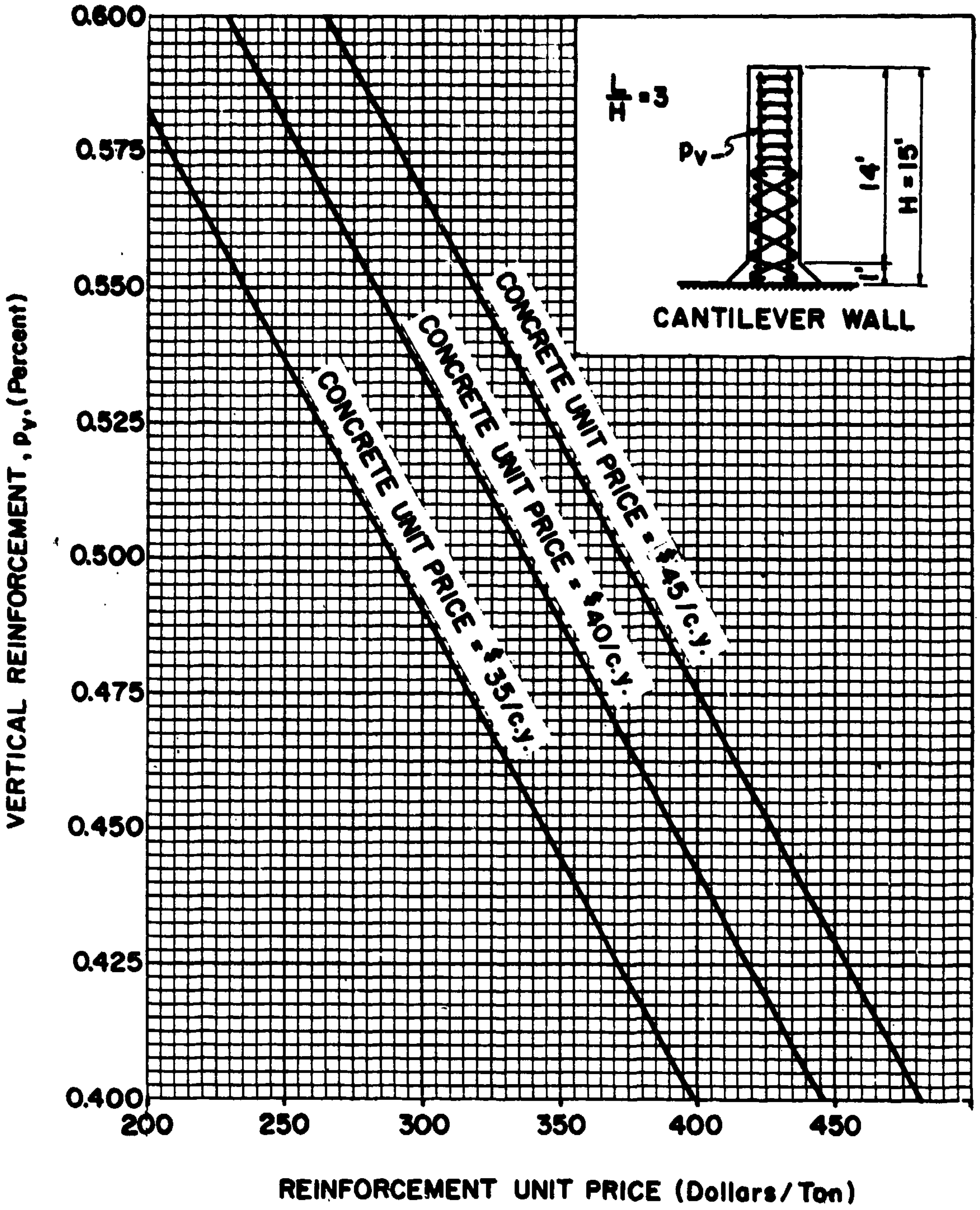


FIGURE 9
VARIATION OF OPTIMUM REINFORCEMENT
WITH UNIT PRICE OF CONCRETE AND STEEL

and concrete thicknesses of composite walls will approach those of the laced single walls.

As may be expected, the secondary fragment criteria will result in a substantial cost reduction. For charge weights equal to or larger than 1000 pounds (minimum concrete and steel, Fig. 8), the cost for walls designed for secondary fragment criteria is approximately one-half the cost of walls designed for incipient failure. It may be noted that the cost of the "12 in. Standard Wall" is approximately the same as that of minimum laced single walls (10 in section with 0.18% reinforcement). However, for the secondary fragment criteria (velocity=100 fps), the charge capacity of the "Standard Wall" will be one-third that of a laced wall.

As an extension to the analysis, the cost of laced concrete walls were compared to the cost of standard concrete walls (with varying thickness) which utilize the same percent reinforcement (0.167%) as the "12 in. Standard Dividing Wall" (Fig. 10). The cost of the laced walls varies from 80% to 67% of the cost of the "Standard Walls" for charge weights of 100 and 10,000 pounds, respectively. Moreover, the thickness of the standard walls are substantially larger than those of laced walls. As a comparison, for a 100 pound charge, the required thickness of laced and standard walls are 10 and 22 inches, respectively. The thickness of the latter compares favorably with the back wall of the cubicle of Ref. 1 where a three foot thick cubicle back wall resisted the blast output of 100 pounds of cyclotol.

In many installations, the space required for the concrete wall thicknesses corresponding to the optimum reinforcement is not available. Therefore, increased amounts of steel must be provided to decrease the thickness of the wall. Figure 11 illustrates the additional cost incurred if the thickness of the previously mentioned cantilever wall is reduced. For all charge weights studied, the cost increase when one percent flexural steel is used in each face of the wall is approximately 10 percent (for concrete and steel) above the cost of optimum reinforcement designs. However, when the cost for formwork is included, this increase will be less. Depending upon the charge weight, a wall thickness reduction of 20 to 30 percent is associated with the use of the larger

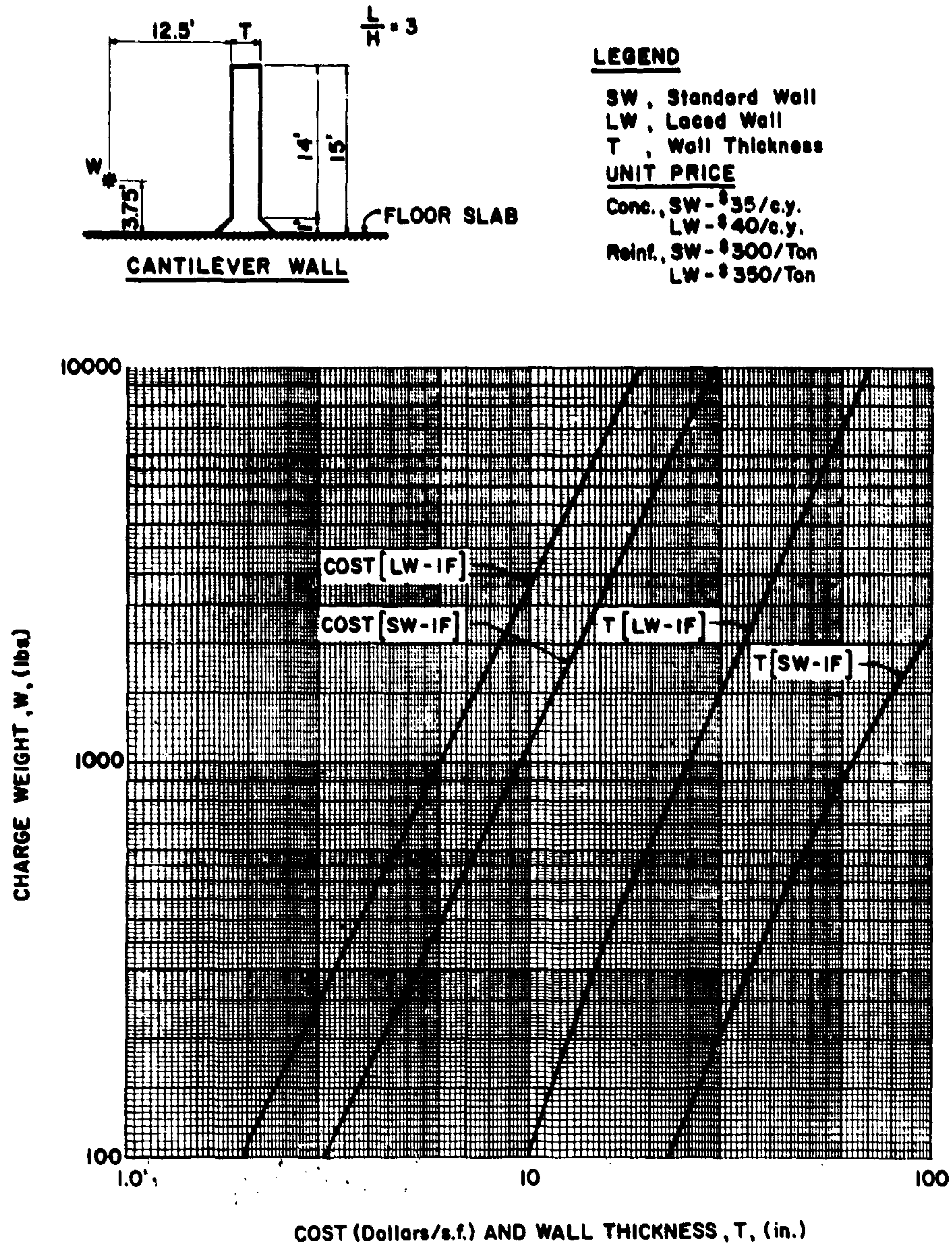


FIGURE 10

COMPARISON OF COST AND THICKNESS OF LACED AND STANDARD WALLS

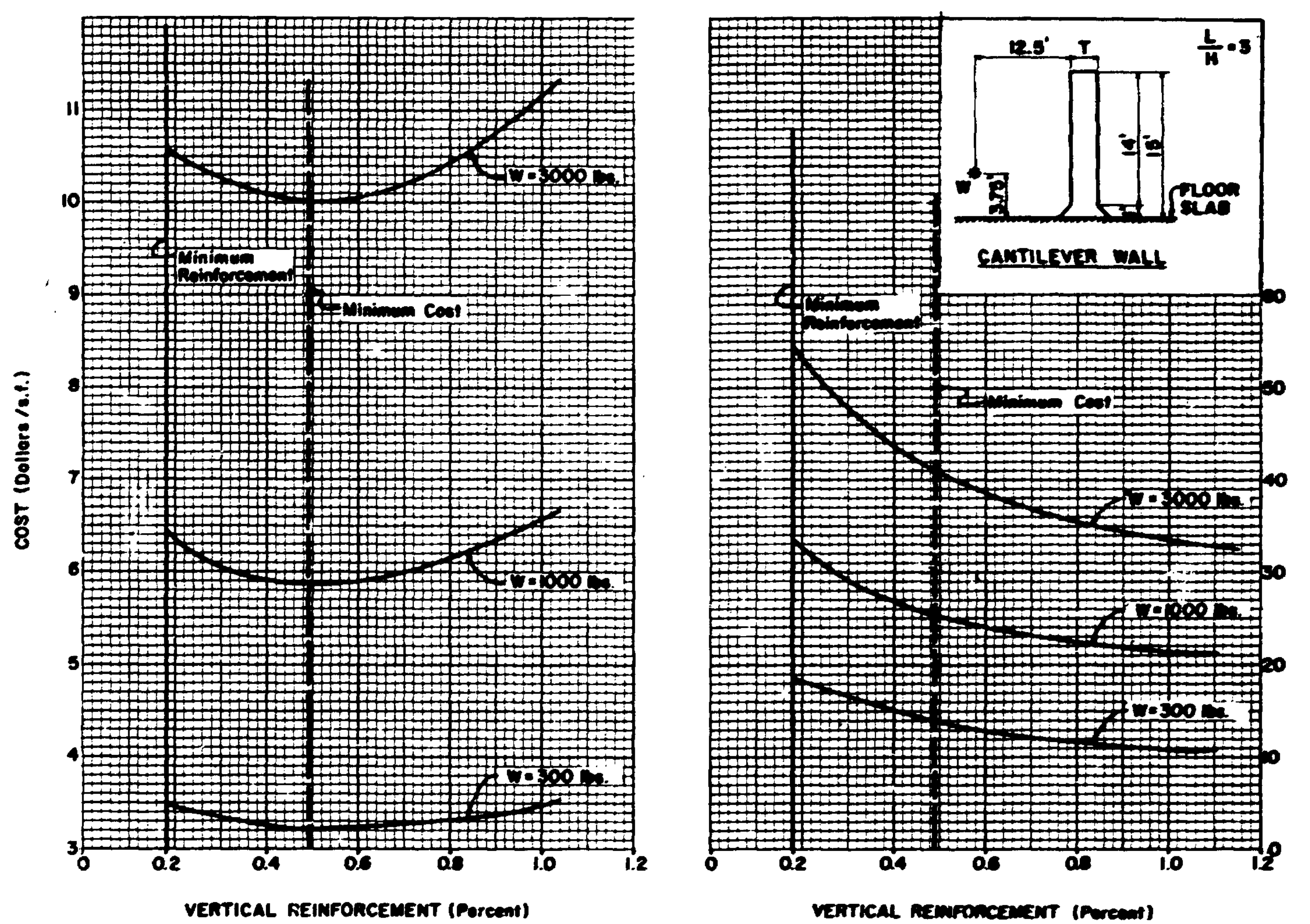


FIGURE II

VARIATION OF COST AND THICKNESS WITH PERCENT REINFORCEMENT

percentage of steel (1%).

As an explosive charge is moved closer to a wall, higher construction costs are realized. In the case of the cantilever wall, to move the charge from its 12 ft-6in. separation distance to a location where the charge is 3 feet from the wall, the added cost will be in the order of 15 to 20% (Fig. 12).

Another increase in the unit cost of the wall will occur when the length to height ratio of the wall is decreased. This increase will be substantial for the larger charge weights (Fig. 13) and results from a concentration of the larger blast loads, occurring adjacent to the explosion, over a shorter length of wall.

The cost trends discussed for the cantilever wall also apply to walls which span in two directions. However, because of the two-way action, an added factor is involved in determining the cost effectiveness of these walls. Before the optimum thickness and reinforcement can be established, the optimum placement of the steel in both the horizontal and vertical directions must be determined in order to obtain the maximum wall capacity for a given total amount of steel used in the wall. As shown in Fig. 14, the proper amount of reinforcing steel in each direction will be a function of the length to height ratio of the wall.

The steel proportions indicated in Fig. 14 are optimum steel placements for single cell arrangements and for multicubicle structures where all cells have the same dimensions and donor system (charge weight and location). For multicubicle structures with unsymmetrical cell arrangements and/or variation of the donor systems, these proportions may require adjustment to attain the optimum total amount of steel in the entire structure. As an example, consider a three cell structure whose dimensions, of progressive cells, are defined by length to height ratios of 1.5, 3.0 and 6.0. Each cell is to contain 3000 pounds of H.E. located three feet from the surface of the back wall. The results of an analysis indicated that the required ratios of percentages of the horizontal to vertical steel, to obtain minimum total steel, were one-third, equal to and four times as large as those

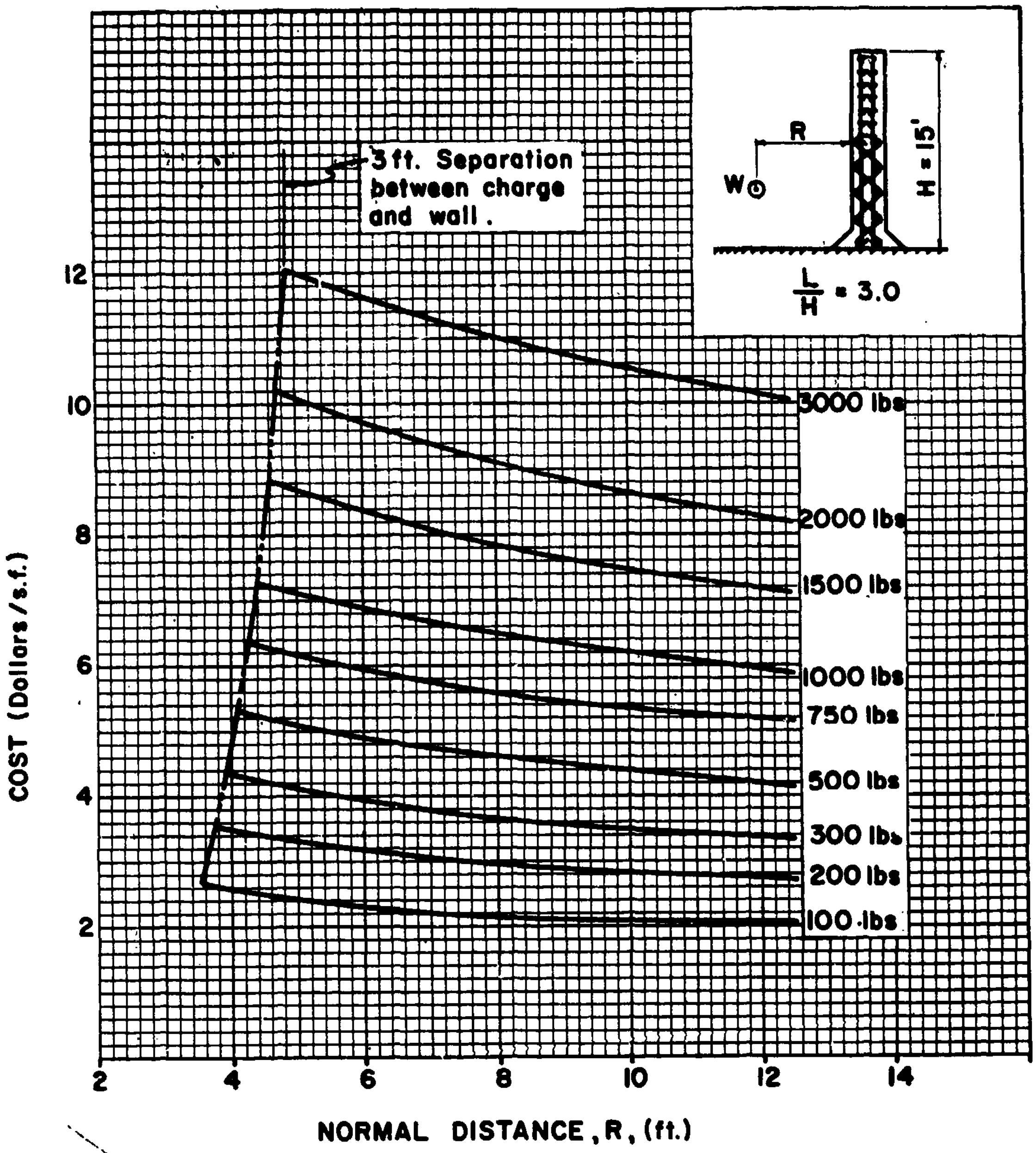


FIGURE 12
VARIATION OF COST WITH SEPARATION DISTANCE

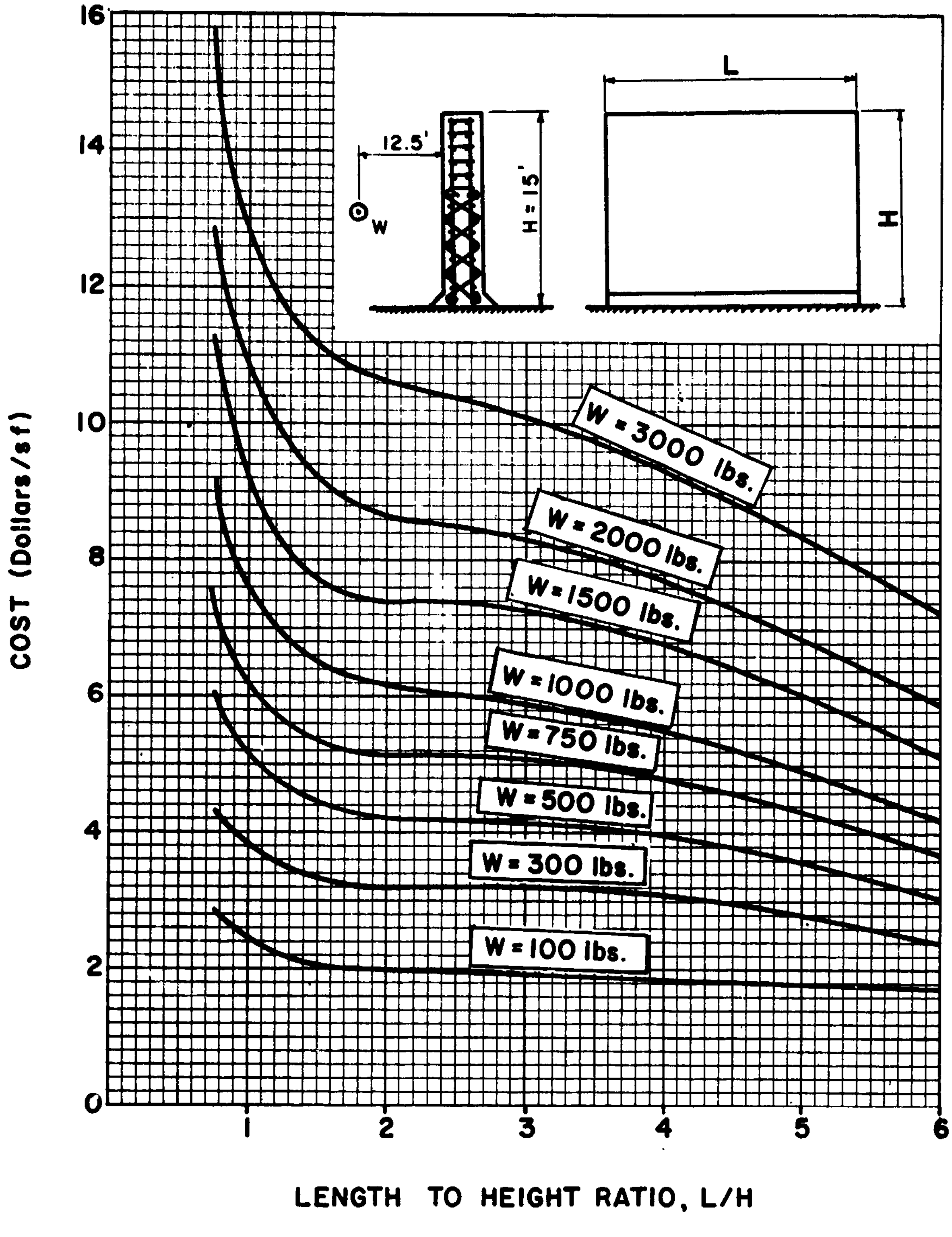


FIGURE 13
VARIATION OF COST WITH WALL
LENGTH TO HEIGHT RATIOS

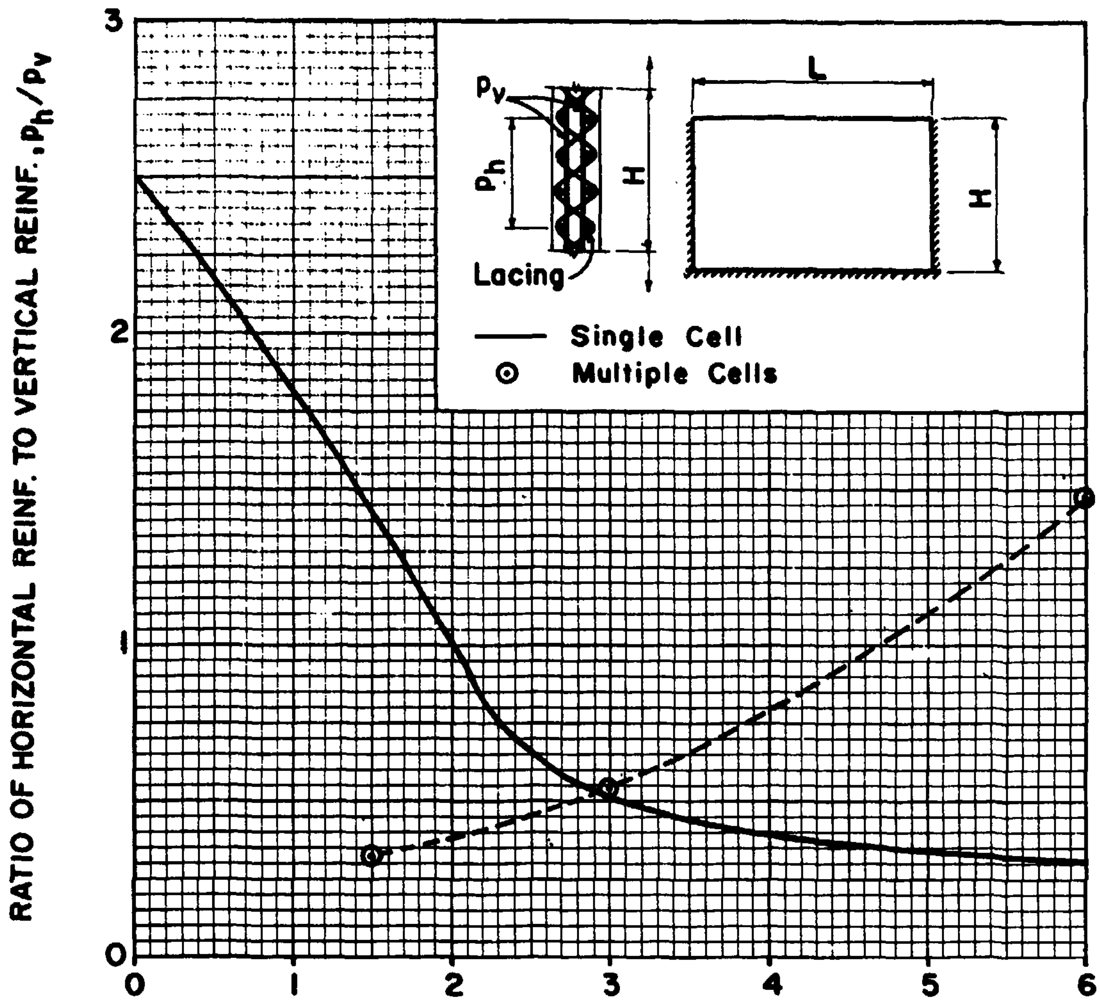


FIGURE 14
PROPORTIONING OF REINFORCEMENT
IN TWO-WAY PANELS

given in Fig. 14 for the small, medium and large size cells, respectively.

Once the correct steel proportions are obtained, the optimum reinforcement and wall thickness are calculated in a manner similar to that illustrated by the cantilever wall analysis.

COST REDUCTION PROGRAM

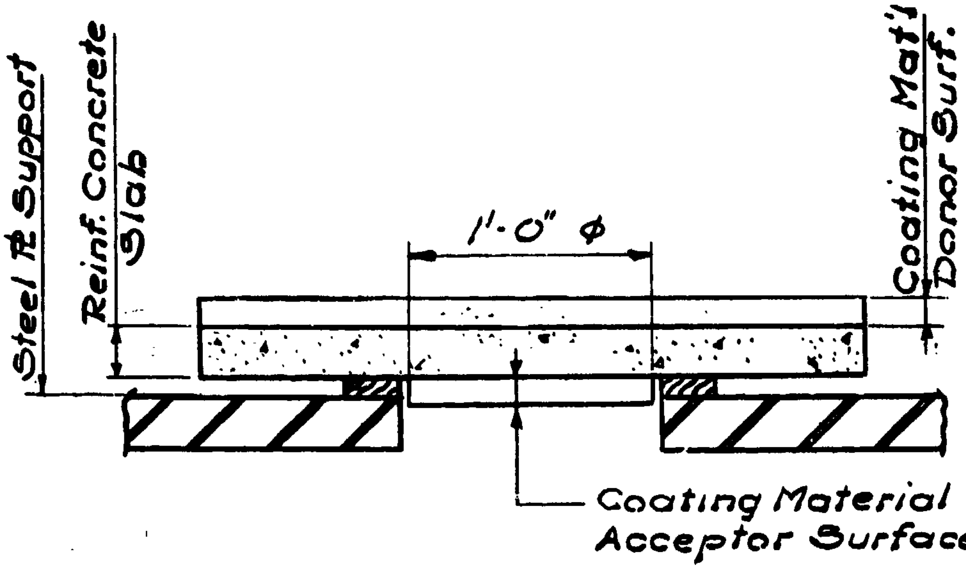
To reduce construction costs of facilities employing new design techniques, a cost reduction test program has been initiated. This program includes tests of laced reinforced concrete members to determine more precisely their response to the blast output. Also included are tests of new materials which, when used independently or in combination with laced elements, will produce greater economy in new facility designs.

Blast Attenuation Study

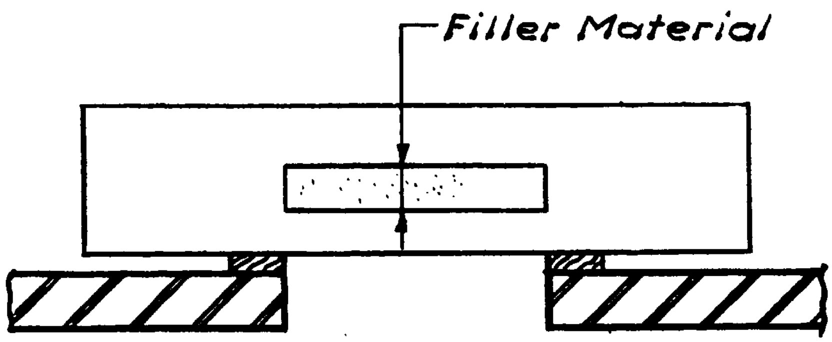
Blast attenuation tests at the U.S. Army Engineer Waterways Experiment Station (Ref. 7) have demonstrated the effectiveness of using several different materials as absorbers of shock energy to reduce spall velocities from concrete dividing walls. These tests have been directed primarily towards the reduction of transient peak stresses in the materials and have indicated reductions of spall velocities as high as 90 percent when cellular concrete is used as attenuating material.

Based on these results, a new series of tests were developed, the purpose of which is to ascertain the reduction in total impulse produced by attenuating materials. These tests will utilize one-fifth scale laced reinforced slabs to simulate the dividing wall. The slabs are of both single and composite construction. For the tests of the single slabs, the cellular concrete bonds to both surfaces of the slabs while for the composite slab tests the attenuating material is used as the filler material. Figure 15 illustrates typical single and composite slab test specimens.

Results of these tests, which will be qualitative in nature, will be correlated with results of similar explosive



a. STANDARD AND STRENGTHENED SLABS



b. COMPOSITE SLAB

FIGURE 15

TEST SPECIMENS FOR ATTENUATION TESTS

tests previously performed on 1/3, 1/8 and 1/10 scale laced concrete slabs. The composite slabs of the former tests used sand as the attenuating material.

Supplementary tests are contemplated using cubicle models in combination with those materials which demonstrate promising impulse attenuation characteristics.

<u>Static and Dynamic Slab Tests</u>

As a continuation of the cost reduction program a series of static slab tests will be performed at Columbia University in New York and dynamic slab tests will be performed at the U.S. Naval Civil Engineering Laboratory at Port Hueneme, California.

The purpose of the static slab tests is to determine the relationship of the response of laced reinforced concrete elements to statically applied loads and thereby establish the maximum plastic rotation which laced elements can achieve without failure. The effects on the maximum plastic rotation produced by variations of support conditions, percentage of flexural and lacing reinforcement, tension and compression reinforcement, concrete thickness to span ratio and moment to shear ratio at the supports will be investigated. Also to be studied are the ecomomical advantages (or disadvantages) of using lapped, welded and mechanical splices for flexural and lacing reinforcement. Fig. 16 illustrates the procedures to be used in this test series.

The dynamic tests were developed to determine the increase in stresses (yield and ultimate) of laced reinforced concrete members when subjected to rapidly applied loads. Both the flexural and lacing reinforcement and the concrete will be instrumented with electronic strain gages. For purposes of evaluation, these dynamic tests will be supplemented with static tests of similar slabs.

Because of the expense involved, only a limited number of dynamic tests are presently scheduled. However, it is felt that the results of these tests will give an insight into the dynamic properties of laced concrete structures.

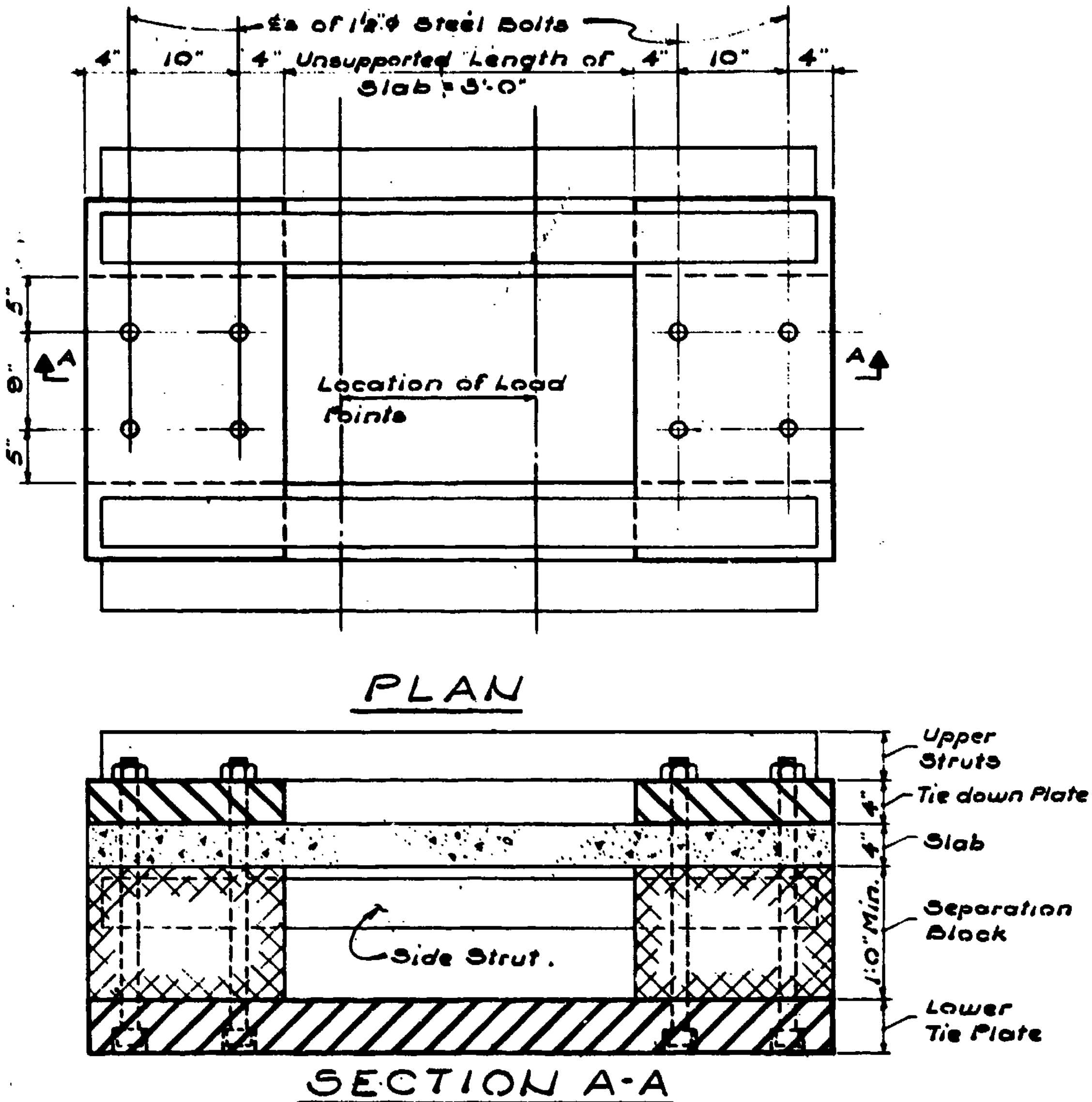


FIGURE 16
TEST SET-UP FOR STATIC SLAB TESTS

Other Material to be Investigated

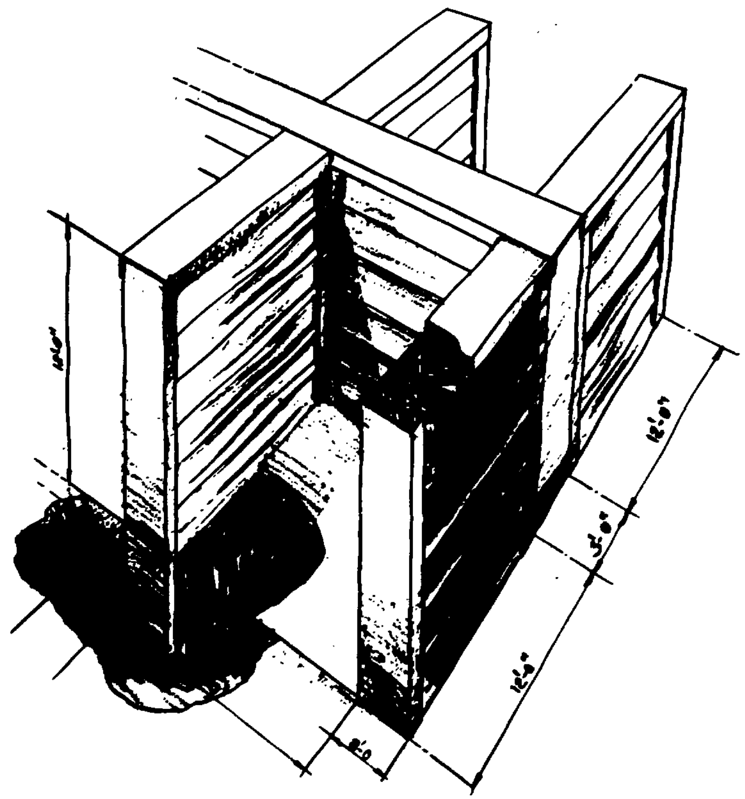
The major emphasis of the Safety Design Program has been placed on the development of the use of cast-in-place reinforced concrete for use in design of new explosive facilities. As an extension of the program, other materials are now in preliminary stages of investigation to determine their usefulness in blast resistant design. Tests utilizing pre- and post-tensioned cast-in-place concrete members, pre-cast concrete sections, structural steel, pre-fabricated truss bars, bridge strand, steelcrete, etc. are now being prepared. These materials will be investigated utilizing explosive tests similar to those used in the initial investigation of laced concrete elements performed at NOTS (Ref. 8).

To illustrate possible structural arrangements using these new materials, the following four preliminary schemes for structural steel cubicles will be described.

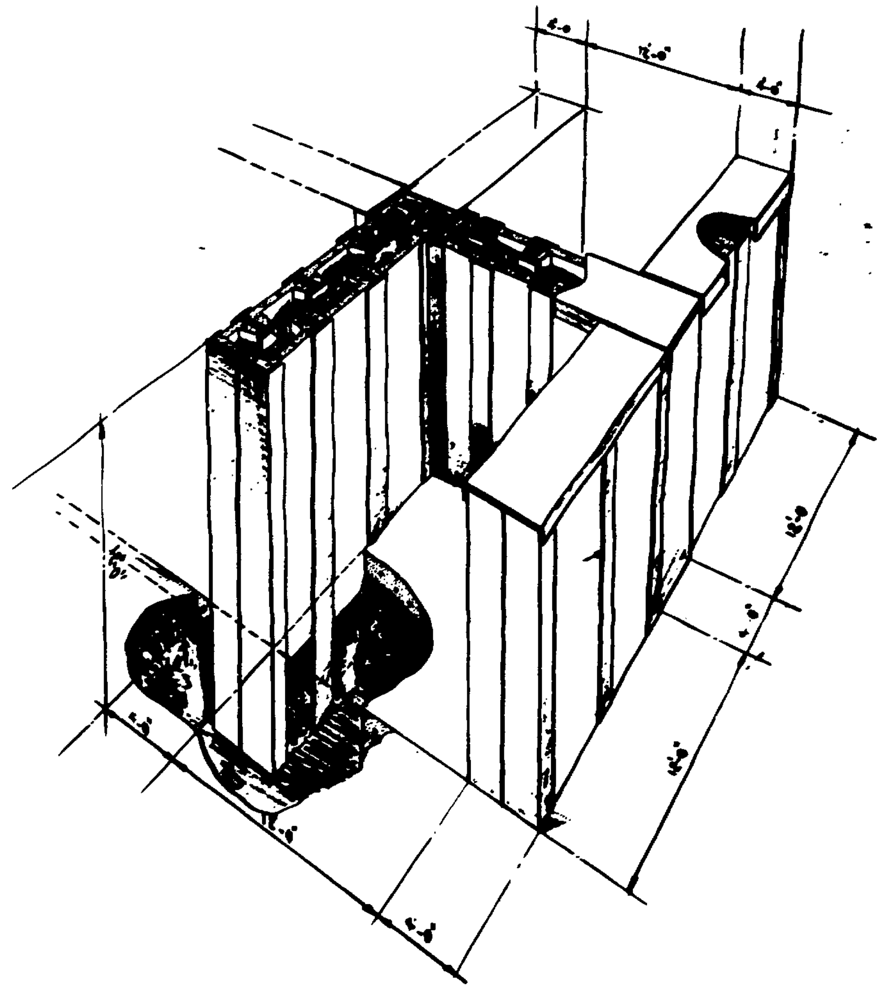
The first scheme (Fig. 17a) consists of a cubicle whose back and side walls are constructed of structural steel pipes. These pipes are laced together with steel sleeves to form monolithic wall sections. The pipes and sleeves are covered with interconnected steel plates thereby forming solid walls. The pipes may be anchored in concrete or driven directly into the subgrade.

Scheme No. 2 (Fig. 17a) consists of walls constructed of structural steel sections separated by pre-cast slabs. The structural steel and concrete sections are so arranged as to permit the addition of filler material. Support at the base of the steel sections is similar to that of Scheme 1 while the pre-cast section will extend down to the bottom of the floor slab.

The walls of the third scheme (Fig. 17b) are fabricated with interlocked WF or I beams. Interlocking is produced by overlapping and welding of flanges. Spaces between the flanges and web are filled with sand, concrete or other material to increase the mass of the structure as well as to provide the required support to resist transverse bending of the flanges. Support at the base of the walls is similar to that of Schemes 1 and 2.

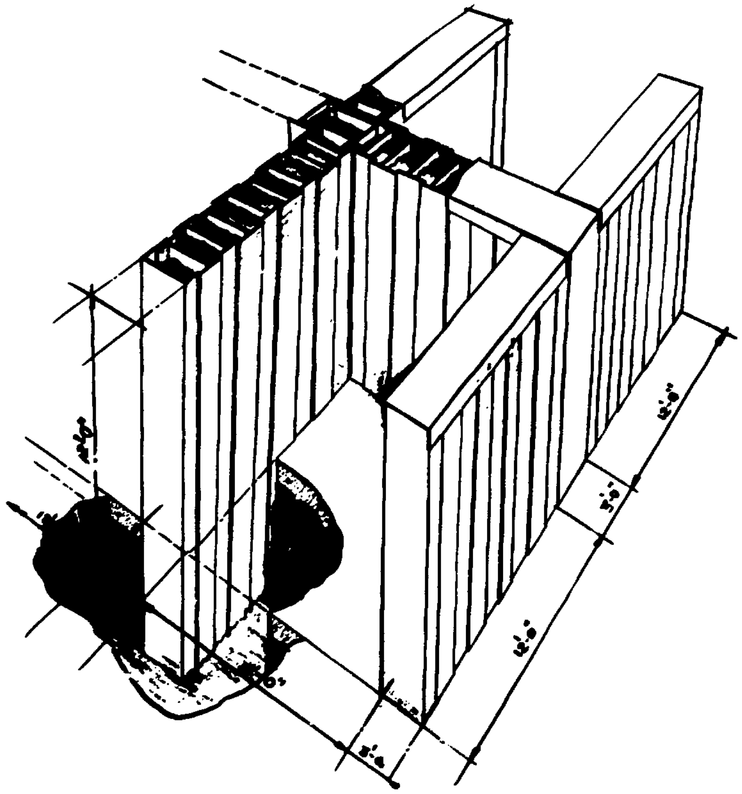


STEEL PIPES AND SLEEVES

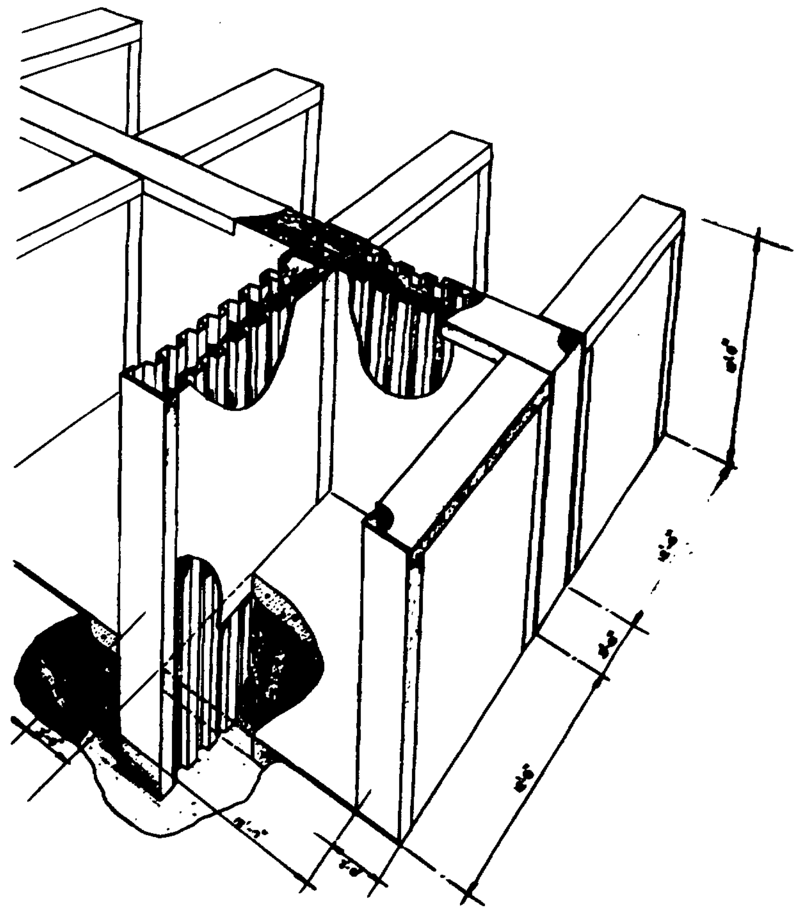


STEEL AND PRE-CAST BEAMS

FIGURE 17a
SCHEMATICS OF STRUCTURAL STEEL CUBICLES



STEEL BEAM CUBICLE



STEEL PILING CUBICLE

FIGURE 17b
SCHEMATICS OF STRUCTURAL STEEL CUBICLES

The last scheme (Fig. 17b) consists of walls constructed of double layers of sheet piling. To resist the loss of section modulus of the piling due to the action of the blast loads, the exterior surface of the piling is stiffened with welded steel plates. In addition, to prevent inward collapse of the piling, the space between the layers is filled with concrete or other rigid material. The filler will increase the mass of each wall.

The overall design philosophy of the above schemes is to minimize field erection and thereby achieve economy in construction.

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DESIGN OF AMMUNITION MAINTENANCE FACILITY FOR CONVENTIONAL AND ADVANCED WEAPONS

by

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ABSTRACT

This paper presents a discussion of the criteria and concepts associated with the siting, design and construction of a maintenance facility serving both conventional ammunition and large solid propellant motors of guided missiles and rockets.

The facility, which has been designed to prevent propagation of explosions and to provide improved personnel protection, is the first construction utilizing techniques resulting from recent research. Factors affecting the relative locations and orientations of the various structures, such as quantity-distance requirements, operational aspects and relative economies, are presented. The type of construction selected for the various structures is discussed and compared to other types initially considered. The methods of handling the relatively large amount and unusual type of reinforcement and the procedures required for construction are discussed. The construction costs for this facility are compared to those which would be incurred utilizing "Substantial Dividing Walls".

INTRODUCTION

The design of an Ammunition Maintenance Facility is similar to many other facility types insofar as the designer should consider the relative economies of the various types of construction suitable for the intended functions and geographic locations, as well as the economies and efficiencies associated with the orientations and relative locations of the various buildings comprising the facility. For facilities which are used for the maintenance or storage of explosive materiels, three additional, but most important considerations are necessary, that is, (1) provision for appropriate means of minimizing the possibility of an accidental detonation, (2) design features which afford a reasonable degree of protection against structural damage and personnel injuries within the facility and (3) siting to minimize the possibility of structural damage or personnel injury at offsite locations.

Provision for minimizing the possibility of an accidental explosion may be grouped into two catergories, i.e., (1) design features and (2) operational instructions and precautions. The latter will vary somewhat depending upon the operation involved, but is well covered by the various military regulations and instructions. Building design features should include, where applicable, lightning protection, anti-spark provisions, isolation of flammable materials, hazard area type lighting fixtures and electrical panels, and an appropriate sprinkler or deluge system for fire control.

Design features providing a reasonable degree of protection for structures and personnel within the facility may be achieved by separation of the various buildings, the use of barricades, structural design to achieve a compatible degree of blast protection or a combination of all three.

Design features providing protection for offsite conventional structures and personnel are usually limited to siting, providing the required separation distances consistent with the possible size of accidental detonation.

The standard design for the facility described in this paper was prepared for the Office of the Chief of Engineers by Ammann & Whitney under Contract DA-49-129-ENG-561.

The techniques used for obtaining the blast loadings and performing the dynamic analyses and design of the Ammunition Maintenance Building and the Vacuum Collector Building were developed by Ammann & Whitney for Picatinny Arsenal under Contracts DAAA-21-67-C-0127 and 0941 as a part of their Supporting Studies Program for the Armed Services Explosives Safety Board.

PURPOSE AND FUNCTION

Figure 1 shows the standard Site Plan developed for the facility. The plan has been site adapted at the various districts, as required by local conditions, and construction is now underway at three locations, i.e. Letterkenny, Pa., Anniston, Ala., and Sierra, Calif. The facility is designed as a semi-independent complex for the maintenance of both conventional ammunition and large solid propellant motors of guided missiles and rockets. The Maintenance Building proper provides two parallel operating lines, one equipped particularly for work on items up to the 8-inch projectile, the other is arranged to handle heavy guided missiles and rockets. Blast-resistant pass-thru ports in the center dividing wall, which can be selectively opened, provide versatility so that when desired, both lines may be used for work on conventional items. Ancillary structures include a vacuum collector building, a hold-down stand for continuity checks of solid-propellant motors, service storage magazines, a lunch-room-change house for employees, a storehouse for flammables and a sentry house at the compound entrance.

FACILITY SITING

Explosive Loadings: Maximum assigned high explosive loadings for establishing explosive-quantity-safety-distances were as follows:

Ammunition Maintenance Building.............25,000 lbs.
Earth-Covered, Steel-Arch Magazines, each... 5,000 lbs.
Missile and Rocket Motor Hold-Down Stand.... 7,000 lbs.
Vacuum Collector Building, each of two
small cubicles.................... 200 lbs.

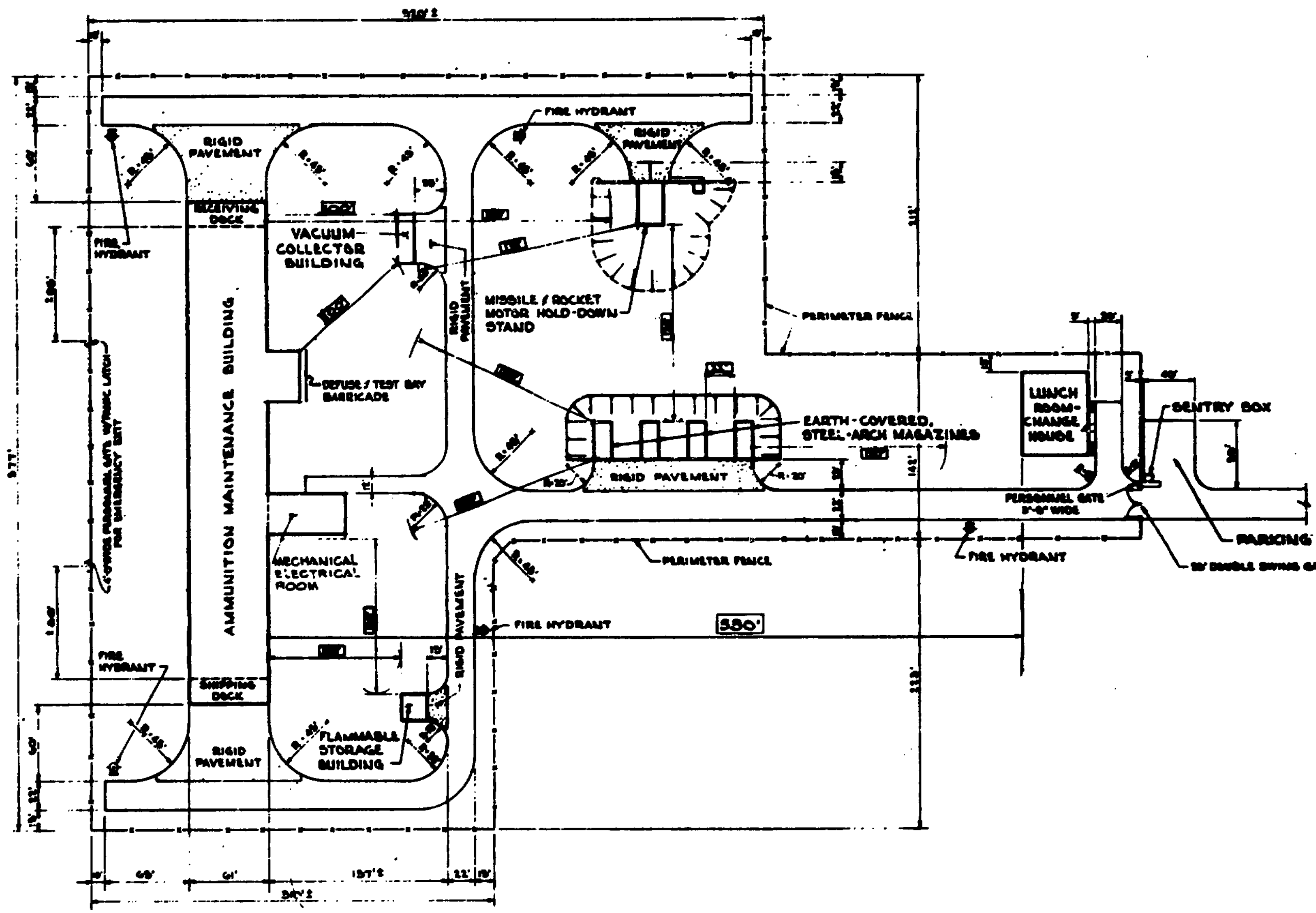


Fig. I SITE PLAN

Explosive Safety Separations: Minimum separation distances indicated on the Site Plan (Figure 1) are in accordance with the minimum requirements of TM 9-1300-206 and AMCR 385-224 (References 1 and 2) except that the minimum inter-magazine spacing of 22 feet for the earth mounded Steel-Arch Magazines is based upon the formula $D=1.25\ W^{1/3}$ which is now the currently accepted criteria (on the basis of full scale tests - Reference 3). In addition, the minimum intraline separation of 150 feet between the Steel-Arch Magazines and the Missile and Rocket Motor Hold-Down Stand is based upon the hazard of the former to the latter. Because of the demonstrated hardness of the steel-arch magazines, it is not considered that an incident involving 7,000 pounds of explosive at the hold-down stand would pose a serious hazard to the contents of the magazines.

The Lunch Room-Change House which is separated from the Maintenance Building by intraline distance, has been designed to provide protection against the blast impulse loading associated with an accidental detonation of 25,000 pounds of high explosive concentrated in the Ammunitions Maintenance Building or 5,000 pounds in the nearest magazine.

The 100-foot intraline separation between the Vacuum Collector Building and the Maintenance Building is based upon the 200-pound-per cell loading of the former. The hazard which the Maintenance Building poses to the Vacuum Collector Building is disregarded since siting to provide this protection would not be economically warranted.

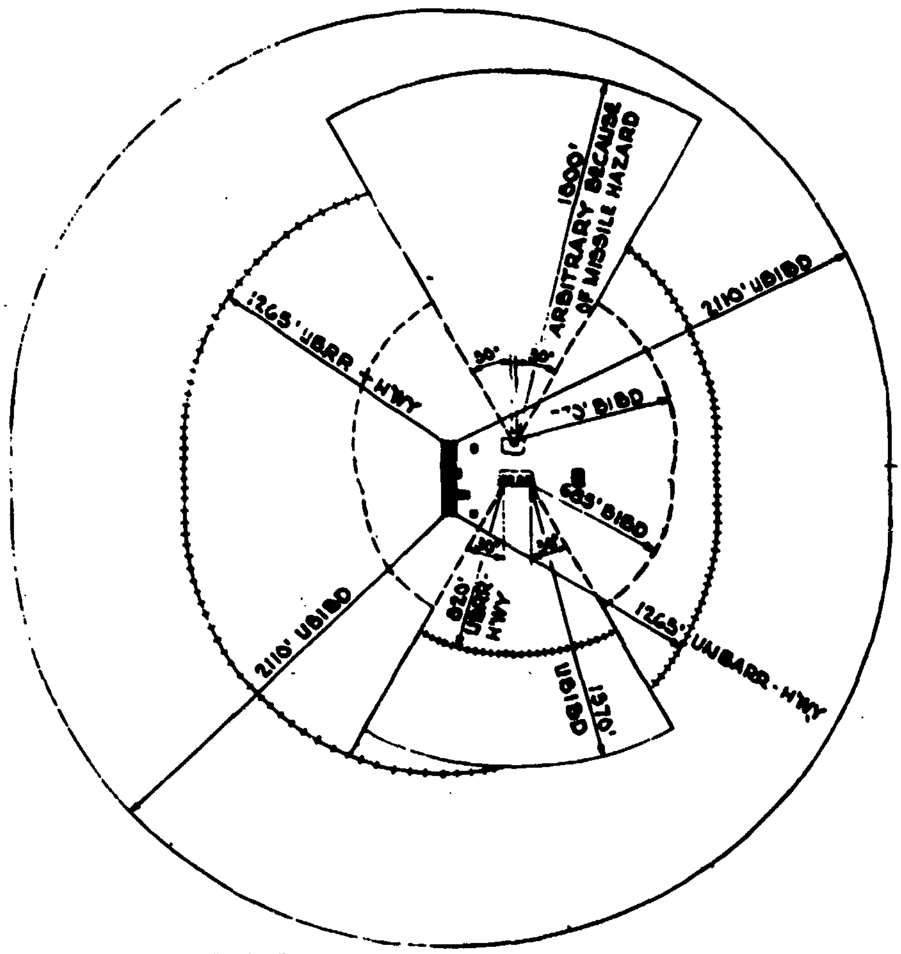
Offsite separation distances for inhabited buildings and public highways (Figure 2) also conform to References 1 and 2 except that the 60 degree by 1,800-feet safety sector centered on the front of the Missile and Rocket Motor Hold-Down Stand has been established as a measure of protection against the hazards of missile or motor fragments which would be thrown out in the event of an accidental explosion at the hold-down stand.

Fire Hazard Separations

The Flammable Storage Building is separated from all other buildings by a minimum of 100 feet.

TABLE OF MINIMUM SEPARATION DISTANCES (FEET) FOR SITING (1)							
BUILDING	MAX. ALLOWABLE LOADING WEIGHT W (LBS)	INTRALINE DISTANCES		INHABITED BUILDING DISTANCES (I.B.D.)		RAILROAD & PUBLIC HIGHWAY DISTANCES (RR-H'WY)	
		BARR.	UNBARR.	BARR.	UNBARR.	BARR.	UNBARR.
VACUUM COLLECTOR BUILDING	200 (PER MODULE)	50	100	255	470	140	280
EARTH-COVERED, STEEL-ARCH MAGAZINES (2)	5,000 (PER MAGAZINE)	150	300	685	1270	410	820
MISSILE/ROCKET MOTOR HOLD-DOWN STAND	7,000	170	340	770	1800 (3)	460	1800 (3)
AMMUNITION MAINTENANCE BUILDING	25,000	265	530	1170	2110	700	1265

(1) ABOVE TABLE IS BASED UPON TM 9-1300-206 AND AMCR 385-224
(2) MINIMUM INTERMAGAZINE SPACING IS 22 FT. DERIVED FROM FORMULA $D = 1.25 W^{1/3}$
(3) ARBITRARY BECAUSE OF MISSILE HAZARD



LEGEND
UNBARRICADED INHABITED BLDG. DISTANCE (UBIBD)
BARRICADED INHABITED BLDG. DISTANCE (BIBD)
UNBARRICADED RAILROAD / PUBLIC HWY DISTANCE (UBRR - H'WY)

Fig. 2 OFF-SITE SEPARATION DISTANCES

Relative Orientation

The relative locations of the structures within the facility were established to provide an efficient operational arrangement within the limitations imposed by safety requirements. The Lunch-Room-Change building is located at the entrance to the facility for convenience and maximum control. The access road is aligned as close as practical to the transverse centerline of the Maintenance Building to minimize travel to and from the Lunch-Room-Change building and the Ammunition Magazines. The Maintenance Building was oriented with the conventional ammunition side facing the facility for two reasons, i.e., (1) minimize the road length and site area and (2) to provide the added protection afforded by the central wall against accidental explosions on the missile side of the building. Tests have shown that the added protection is dependent upon the cell dimensions in which the detonation occurs. As an example, for a detonation within a cell having a length to height ratio between 0.85 to 1.6, the ground surface pressure at the 100 foot range would be 10 psi as compared to 30 psi for an unconfined surface burst and 45 psi if the structure were oriented with the open end facing on-site (Figure 3). As the L/H ratio is increased the pressure versus distance variation approaches the unconfined case.

Roads & Paving

The distribution road within the site is bituminous or equal, depending upon the geographic location, except for the area immediately forward of each of the buildings which is rigid pavement.

The surface of the intersection between the exterior rigid paving and the floor slabs of structures at grade must be flush and remain so. In cold regions, the edge of rigid paving must be designed to prevent frost heaving which would block opening of the doors. Both a sufficient thickness of non-frost-susceptible material and adequate transition sections to the open paving are necessary. In areas having swelling soils, the subgrades of the floor and rigid paving must be designed to prevent heaving which would also block opening of the doors. In all cases, care must be exercised to assure

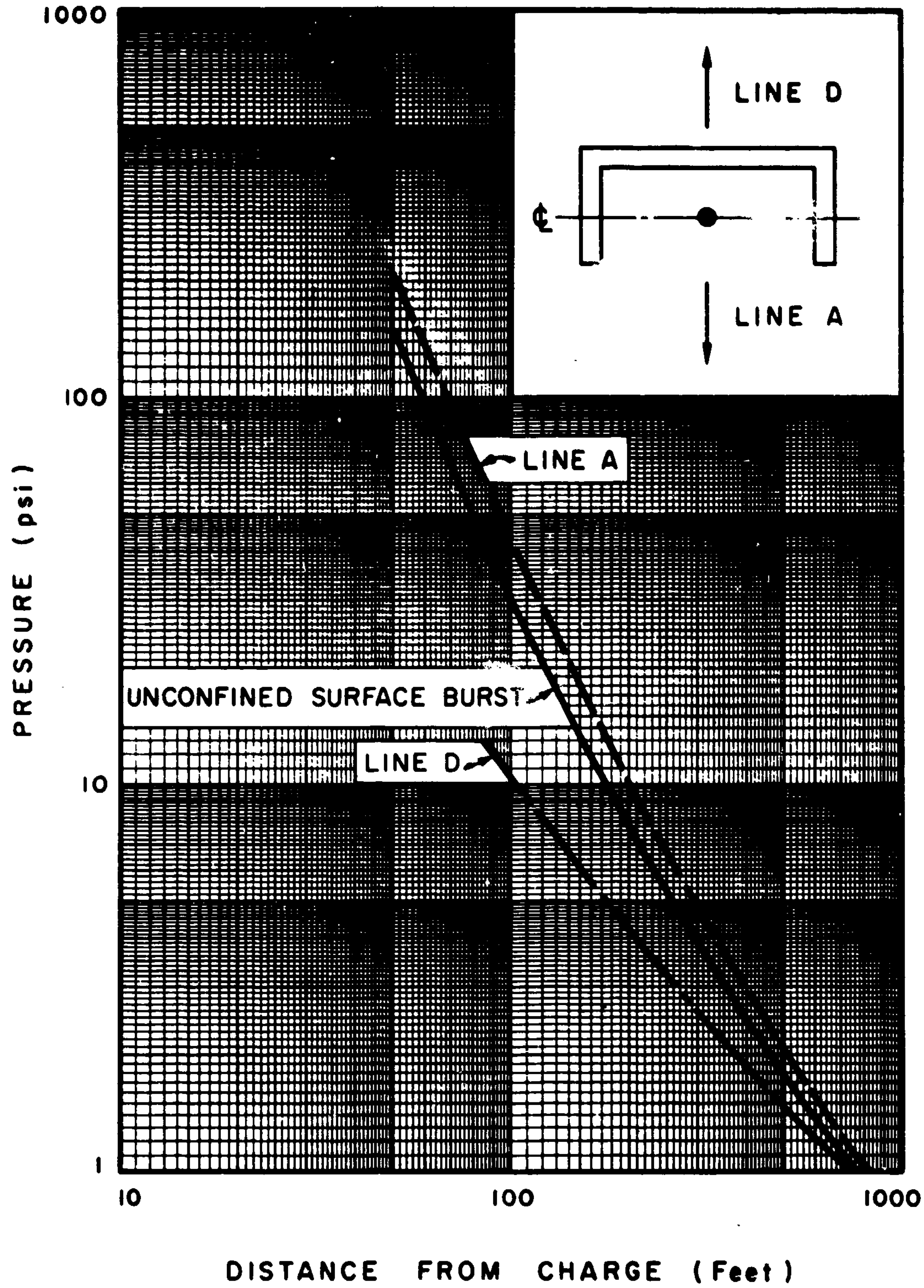


Fig. 3 SURFACE PRESSURE vs. DISTANCE FOR 5000# CHARGE IN CUBICLE (REFERENCE 4)

that the backfill around the foundations and the subgrade are compacted to minimize subsequent movements.

AMMUNITION MAINTENANCE BUILDING

Architectural and Functional Arrangement: The Maintenance Building, as shown in Figure 4, is a long rectangular structure of approximately 25,000 square feet. The building is separated into its two basic functions by a longitudinal dividing wall. Each side is further subdivided into smaller cells by transverse concrete walls with blast resistant pass-thru ports for conveyors. As mentioned previously, the central wall is also provided with blast-resistant pass-thru ports for increased versatility.

The major equipment items within the building include an overhead monorail system at the shipping and receiving bays, power conveyors on each side of the central wall, paint spray booths including overhead monorails for both conventional ammunition and missiles, a compressed air system and an abrasive cleaning unit for the conventional ammunition.

Fire protection is provided by means of open deluge heads in the paint spray booths and automatic closed heads in the remaining areas. Heating is by means of radiant heat panels encased in the floor slab. The roof is made up of lightweight steel joists and metal deck and the walls are insulated metal panels, designed to minimize the reflected blast impulses in the event of an accidental detonation of up to 5,000 pounds in any one cell.

Blast and Fragment Protection: The assigned high explosive loadings for this building are:

Total in building:	25,000 pounds
Maximum in any one bay:	5,000 pounds
Defuse and Test Bays (Bays 13 and 14) and Abrasive Blast Bay (Bay 12):	36.6 pounds

A conceptual study of various dividing wall configurations was made as an initial phase of the design including several

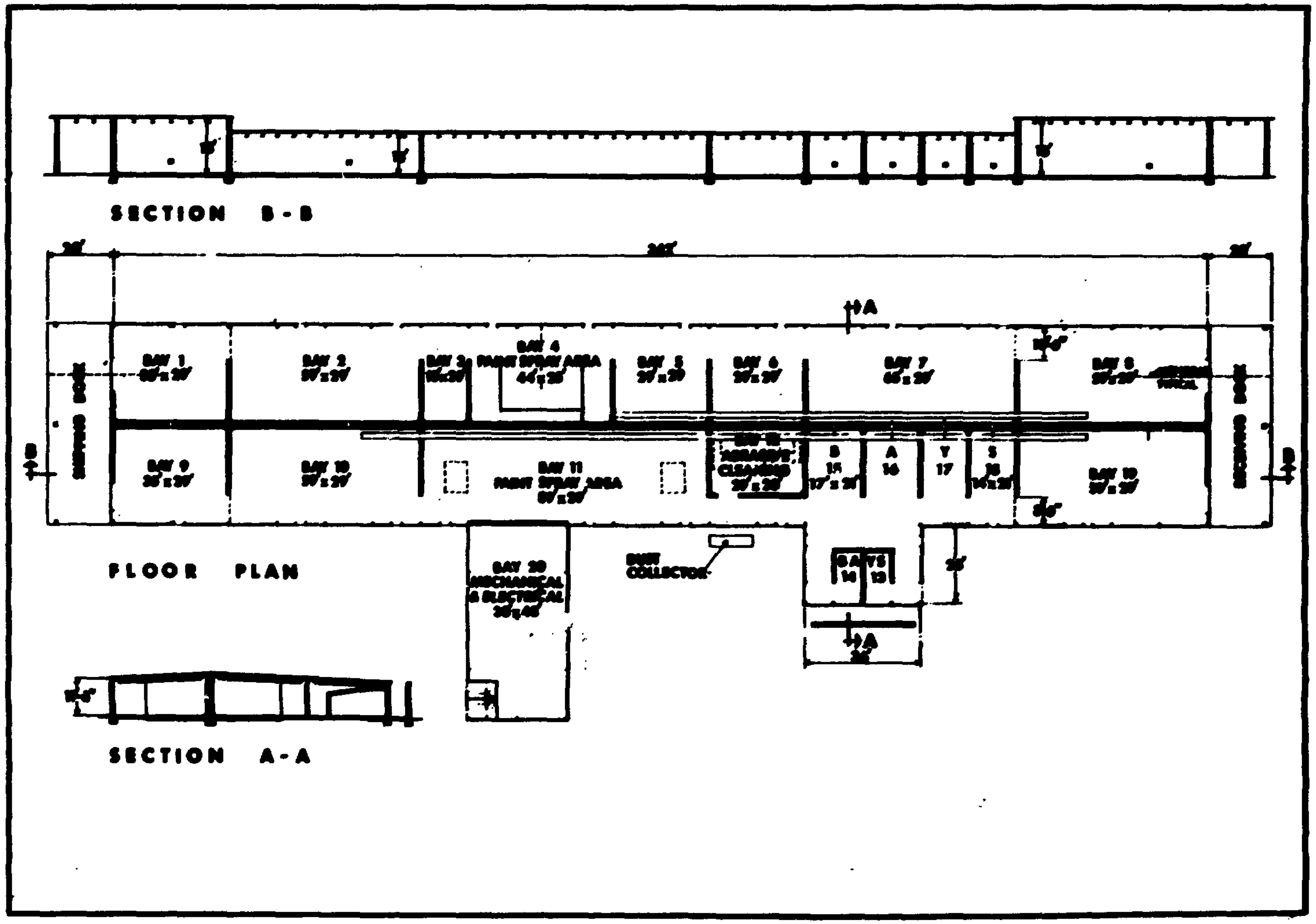


Fig. 4 AMMUNITION MAINTENANCE BUILDING

wall thicknesses with various percentages of reinforcing steel as compared to composite wall construction using two reinforced concrete walls separated by sand fill. The basic design objective was to attain a configuration which would minimize the possibility of propagating detonation between charges in adjacent cells, in the case of an accidental detonation in any one cell of up to 5,000 pounds. Twenty-four-inch center walls and 18-inch wing walls with 1% reinforcement were selected for the final design.

Figure 5 shows the protection afforded by the center wall, for various charge weights and cell dimensions (References 4 and 5). For this illustration, the charge is located at the transverse centerline of the cell and three feet clear of the wall. The incipient failure charge weight is the equivalent weight of TNT which the wall should withstand without collapse. The fragment velocity charge weight is the equivalent weight of TNT which would produce wall collapse and resulting fragments with velocities not exceeding the maximum permissible values consistent with anticipated impact sensitivity of explosives in adjacent bays. For this facility, a maximum of 300 feet per second was selected. The 12-inch wall is shown for comparison since it represents the commonly accepted conception of a substantial dividing wall as defined in Reference 2. Figure 6 illustrates similar results for the 18-inch side walls. In this case, the charge is located at the longitudinal centerline of the cell and at various distances from the side wall. Using the walls adopted, the maximum bay loading of 5,000 pounds is expected to be contained within the 300 fps criterion. For comparison, the permissible charge weights for the 12-inch wall, based upon the 300 fps velocity criteria, varies from 500 to 1,400 pounds for the center wall depending on cell size and a minimum of 400 pounds for the side wall.

Insofar as collapse is concerned, the walls as designed, would survive a detonation of 600 to 2,000 pounds, depending on the cell size and charge location, while the 12-inch construction would survive only 20 to 70 pounds.

It should be noted that although the structure was designed to prevent propagation of charges up to 5,000 pounds, the quantity - safety distances used for siting were based on

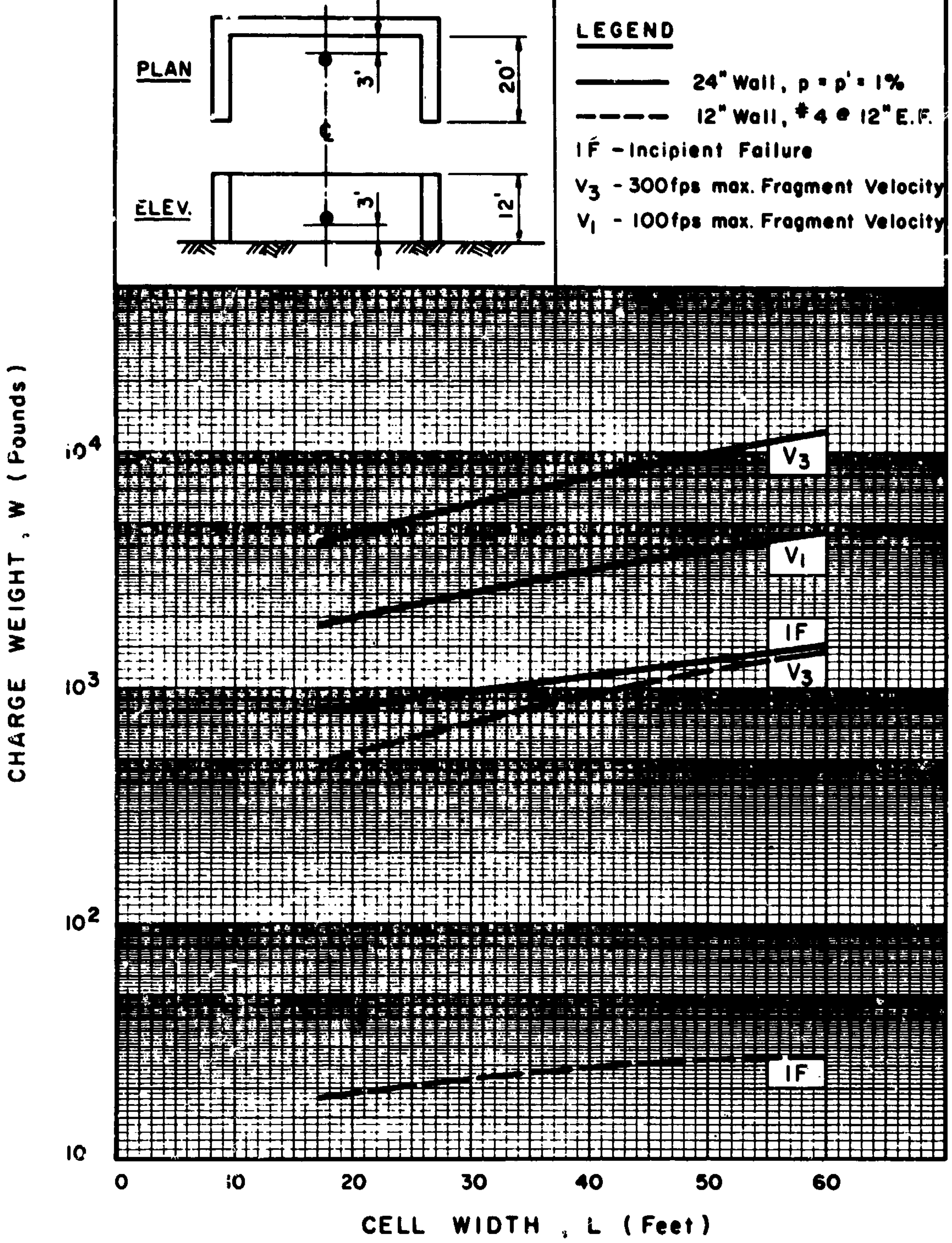


Fig. 5 CHARGE WEIGHT vs. CELL WIDTH (CENTER WALL)

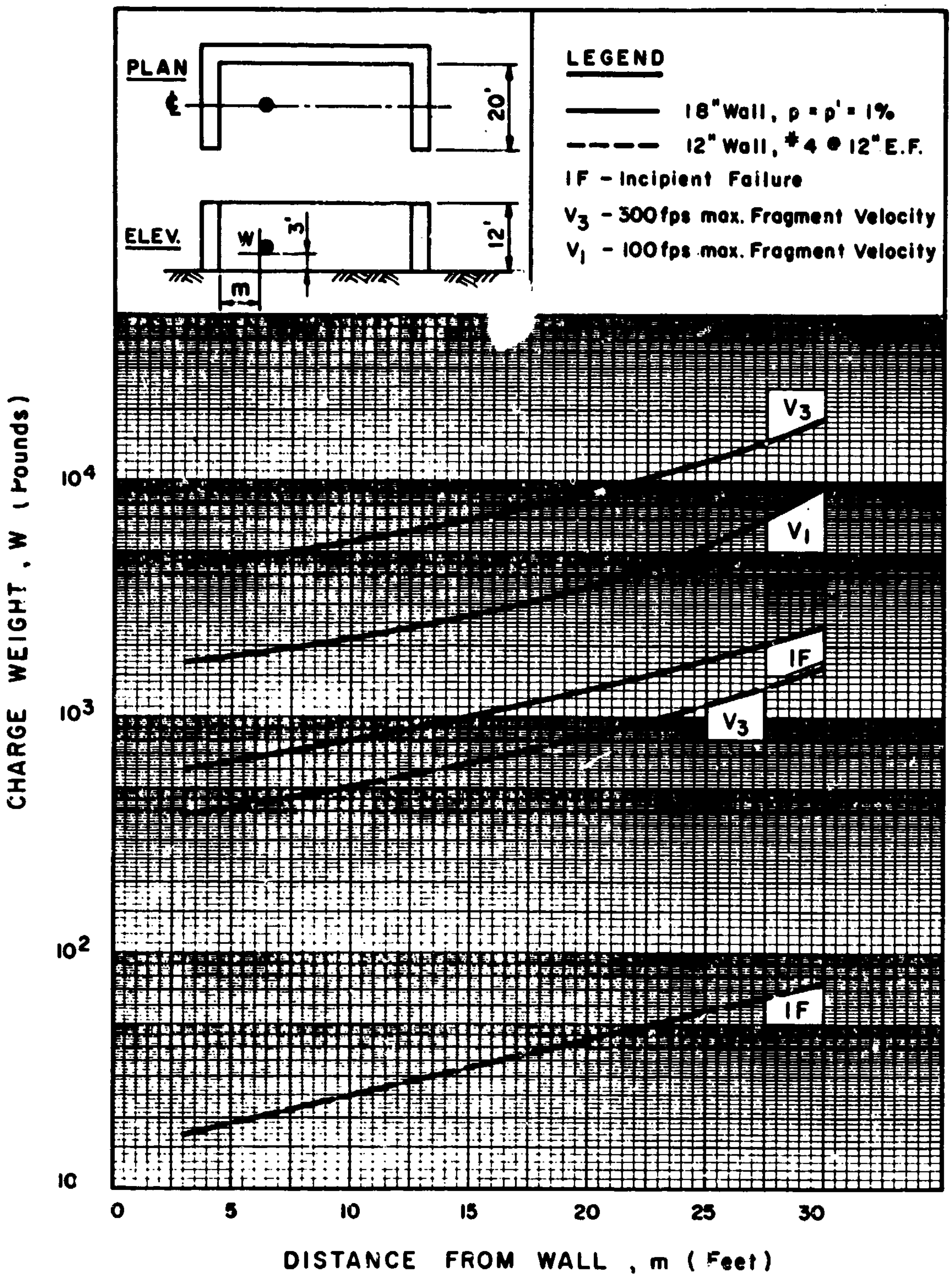


Fig. 6 CHARGE WEIGHT vs. DISTANCE FROM WALL (SIDE WALL)

the total building capacity of 25,000 pounds. This was based upon the possibility that a charge weight greater than 5,000 pounds could be brought into the Maintenance Building for short periods of time during which the building population could be minimized.

Specific Explosive Safety Features: The abrasive blast machine bay (Bay 12) is classified as an extra-hazard area and the walls are designed to protect adjacent areas of the building from the blast and fragment effects of an accidental explosion of an item of ammunition as large as an 8-inch projectile (36.6 pounds H.E.).

Defuse and Test Bays (Bay 14 and 15) are also classified as extra-hazard bays and have been designed to protect adjacent areas in the building from the blast and fragment effects of accidental explosions of items as large as an 8-inch projectile. The exterior wall at the outer end of the bays is an extremely frangible wall designed to readily vent the blast and fragment effects of an explosion. An exterior barricade has been provided immediately outside the two bays to protect personnel outside the building from the projectile fragment hazards of an accidental explosion in either bay.

Construction Details: Figure 8 shows the section and plan of a typical wall. Concrete is required to have an ultimate 28 day strength of 3,000 psi and the reinforcement has been specified as intermediate grade ASTM A-432 which has a minimum yield of 60,000 psi. Concrete used for the floor slab has a required maximum slump of two inches, whereas, that for the walls is required to be between 4 to 6 inches. Maximum size aggregate is 3/4 inch. Construction joints are permitted in the wall below the floor slab and near the top of the slab as shown. There are no splices in the vertical reinforcement or vertical lacing. Vertical construction joints are permitted in the wall at low stress locations. Alternate panels are poured between vertical construction joints. The minimum time of set, for panels poured, is 24 hours before pouring passed panels. Splices in the horizontal lacing are permitted but are staggered as shown. Splices in the main horizontal bars are also staggered to minimize brittle behavior. Consideration was also given to alternate means of welded or mechanical splicing as allowed by the ACI Code.

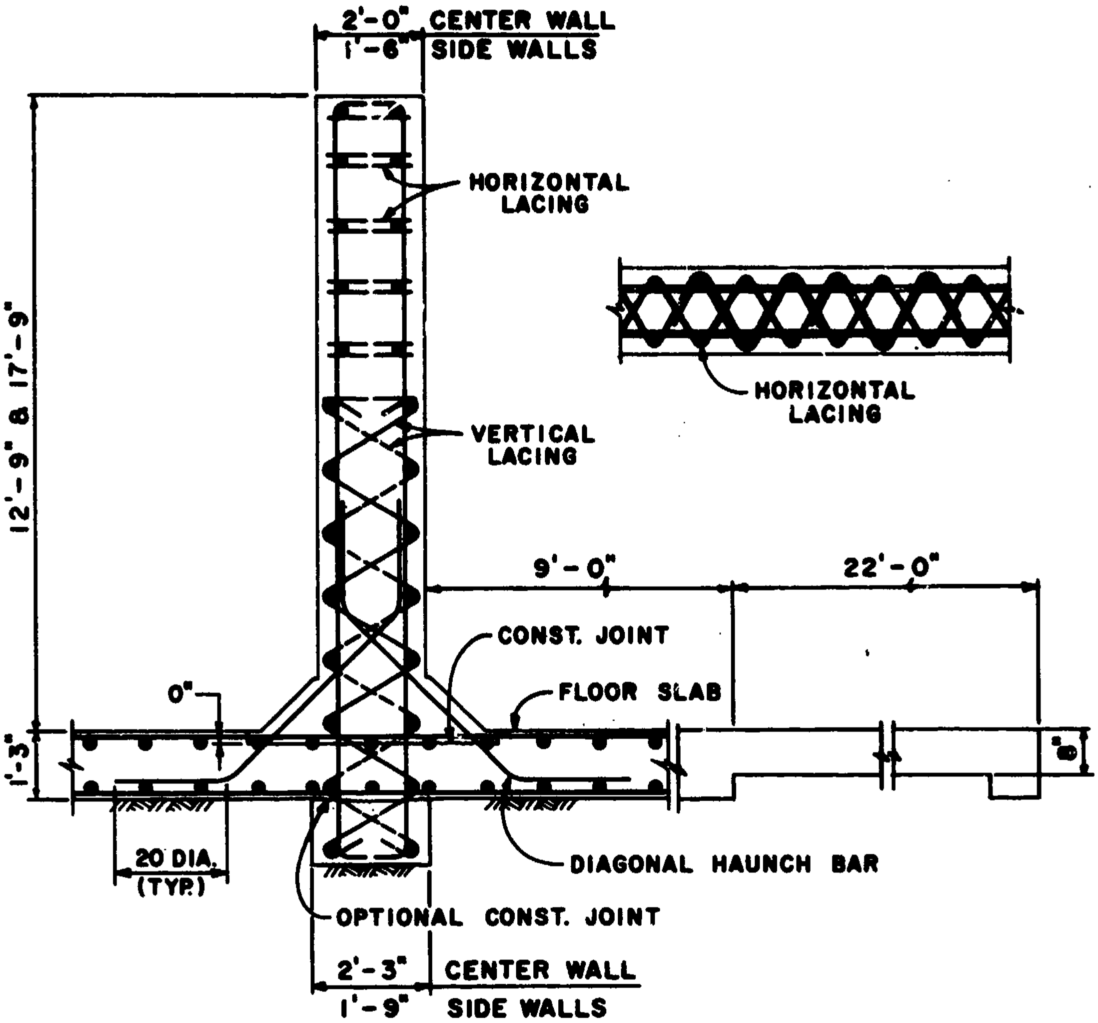


Fig. 7 TYPICAL WALL DETAILS

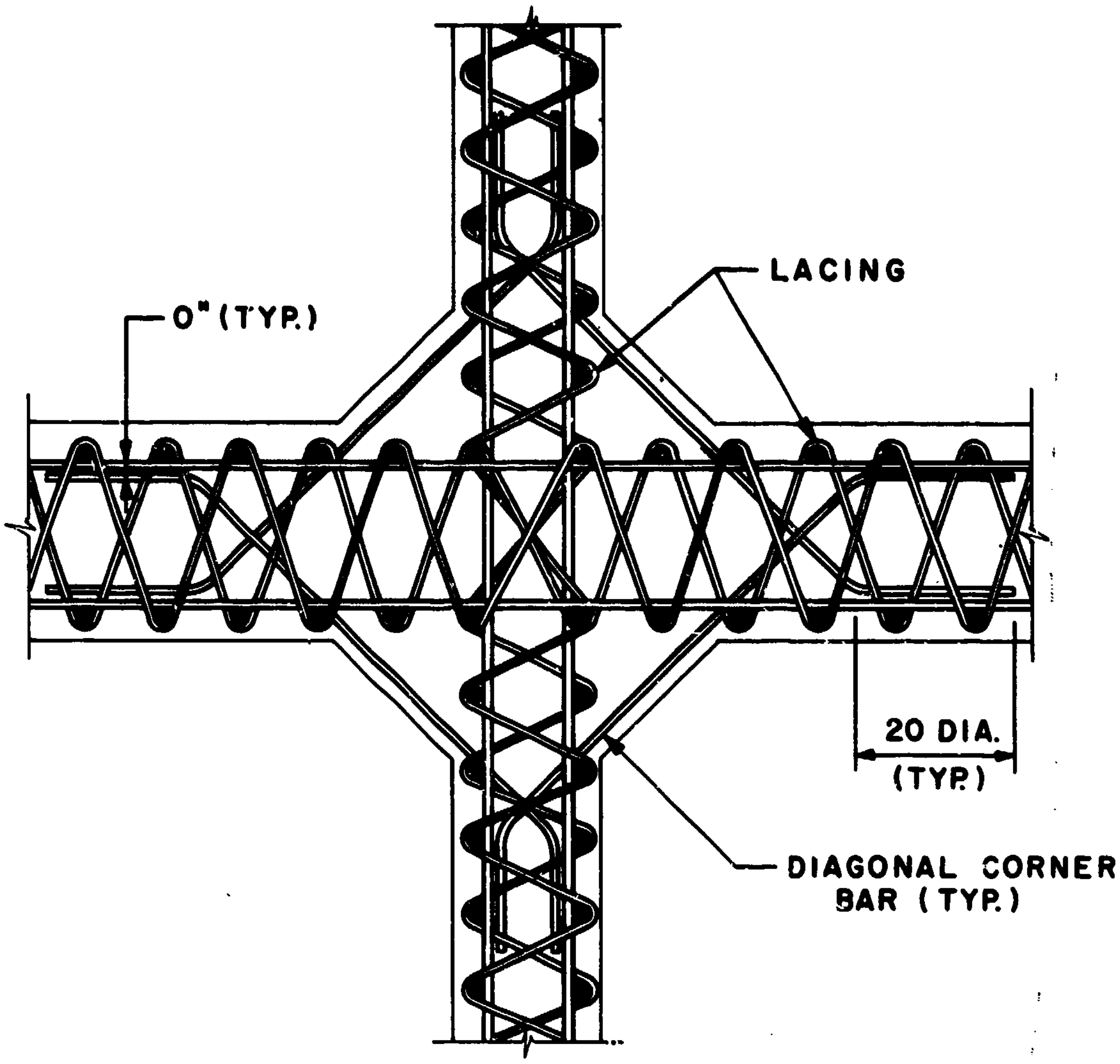


Fig. 8 TYPICAL DETAIL AT FOUR - WALL INTERSECTION

However, the splice detail must be capable of developing the ultimate strength of the bar rather than 125% of yield as specified by the code.

Figure 8 shows a typical plan at a four wall intersection and illustrates the continuity of the main bars, the anchorage of the lacing and the anchorage of the haunch bars. A similar detail for a three wall intersection is shown in Figure 9. In this case the main bars in the through wall are continuous and those in the transverse walls are bent and anchored as shown. Figure 10 shows a construction view of the steel placement at a wall intersection. Figure 11 shows the main reinforcement tied together with the laced bars. Figure 12 shows an example of shop fabrication of the lacing. In this case two bars were processed simultaneously.

VACUUM COLLECTOR BUILDING

The Vacuum Collector Building shown in Figure 13 is used to house the equipment for the collection of explosive powder piped from the Maintenance Building. The structure has reinforced concrete sides, back and interior walls designed to withstand the effects of an accidental detonation of up to 200 pounds of high explosive in each of the two small cells. The roof and front walls are frangible metal deck and metal panels respectively. As noted previously, this structure was located relative to the Ammunition Building based upon a 200 pound intraline distance. However the concrete walls, as designed, would also survive a detonation in the Ammunition Building as high as 25,000 pounds.

During the concept phase, an earth-revetted structure similar to existing designs (Figure 14) was also studied. The roof in this case was made up of concrete beams with precast concrete planks and a hollow cinder block front wall. This concept was eliminated on the basis of relative economy, lesser protection against propagation of an explosion between the two small cells and higher wall and roof fragment hazard.

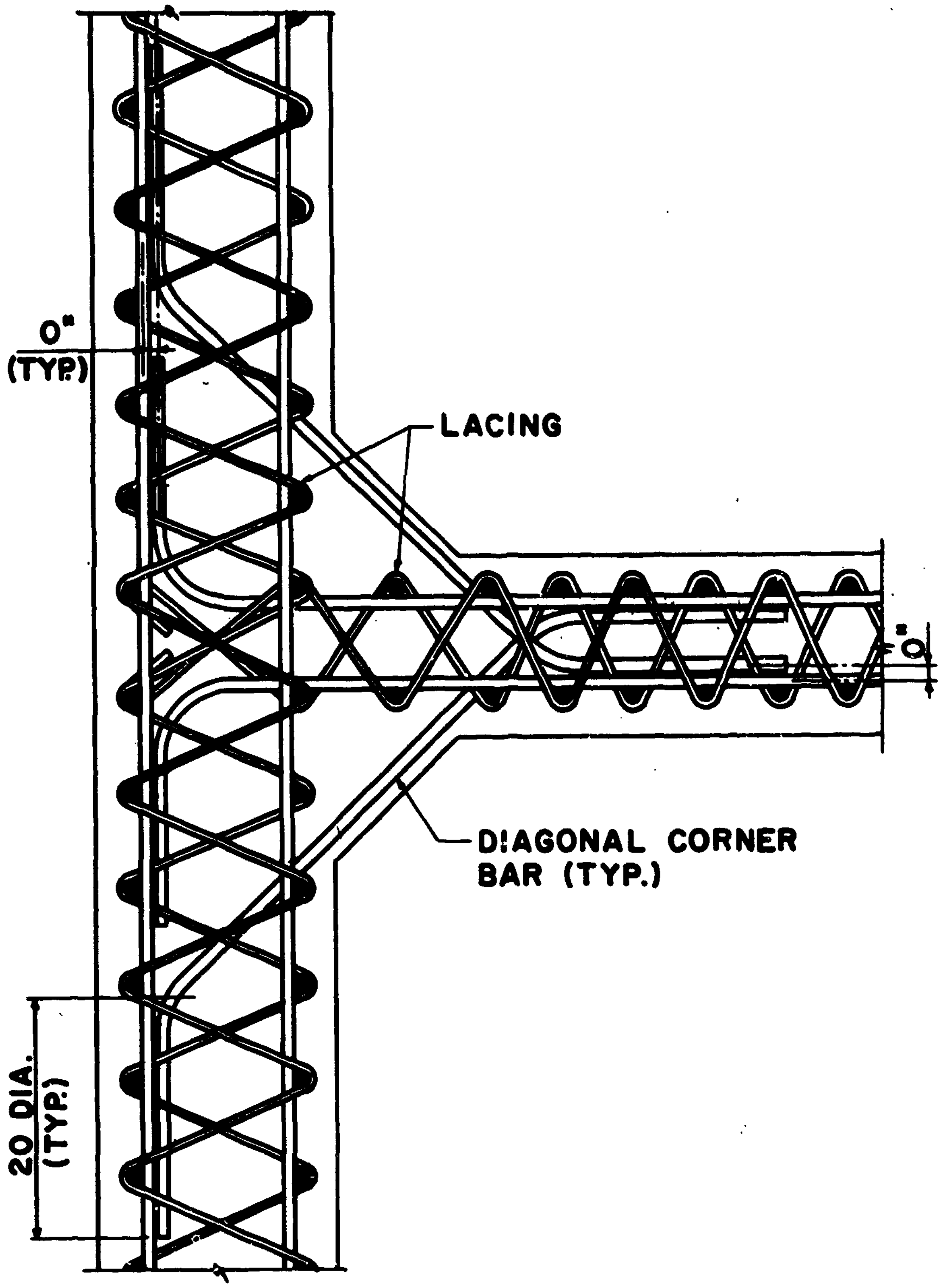


Fig. 9 TYPICAL DETAIL
AT THREE-WALL INTERSECTION

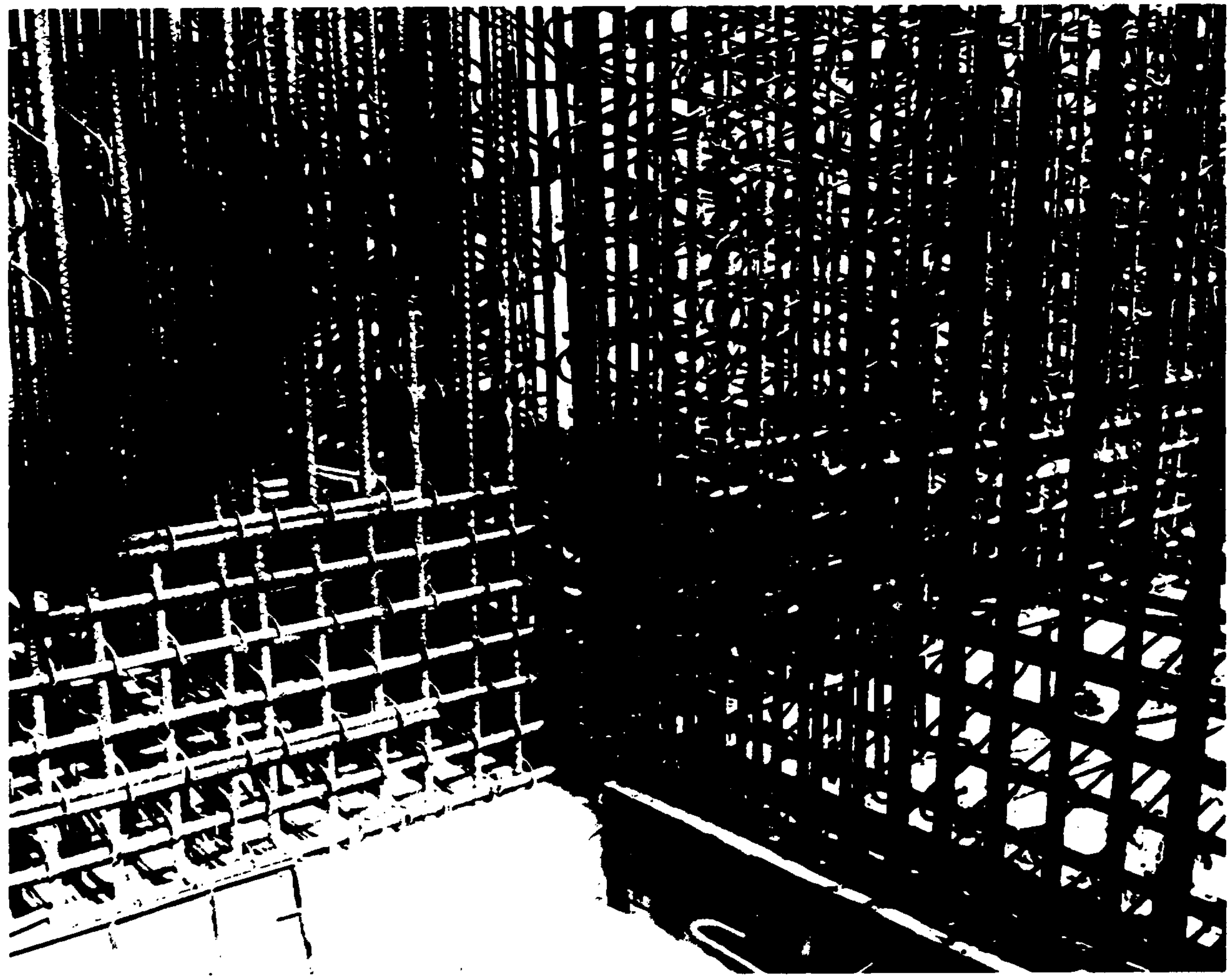


Fig. 10 REINFORCEMENT PLACEMENT AT WALL INTERSECTION

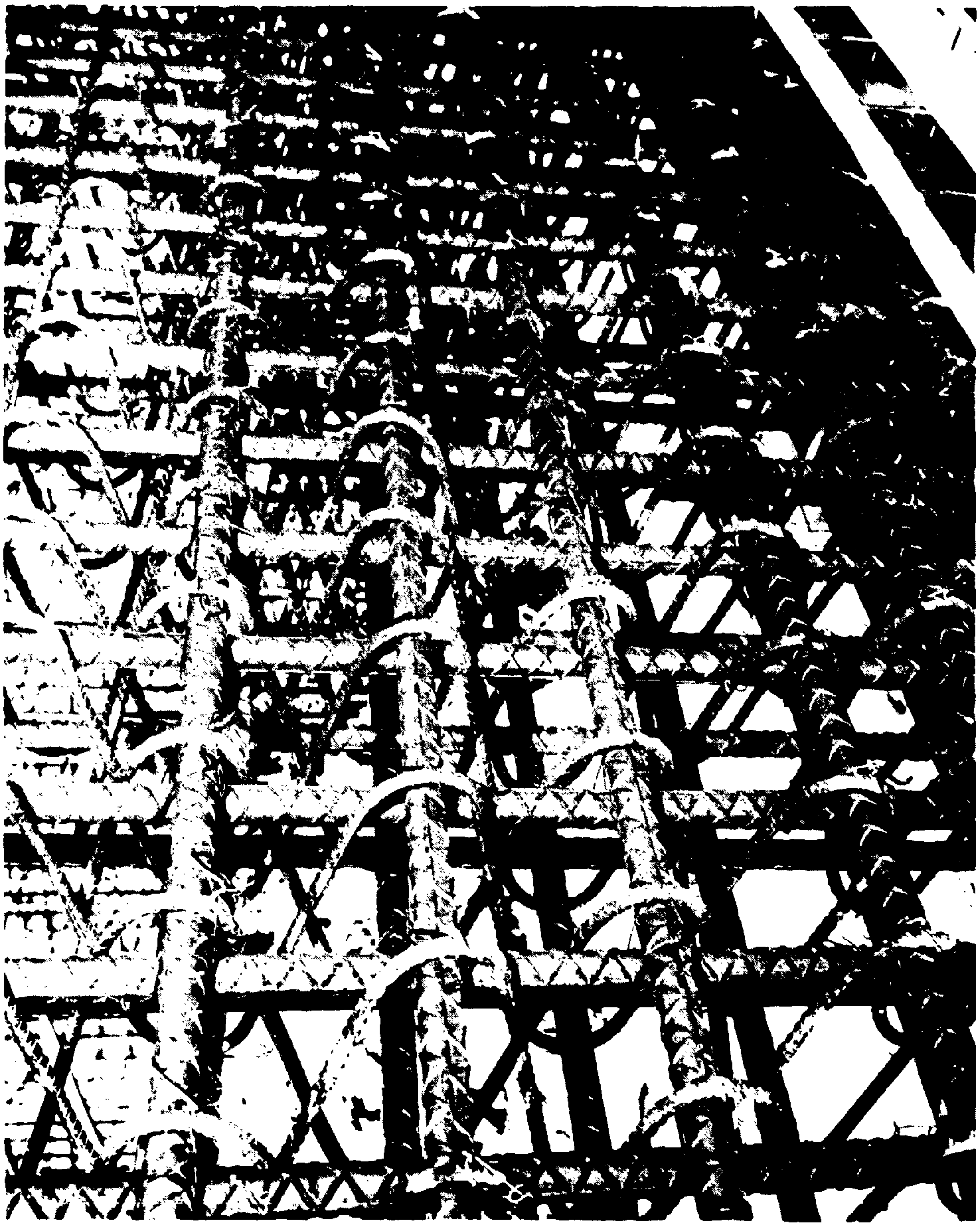


Fig. 11 REINFORCEMENT PLACEMENT AT LACED AREA

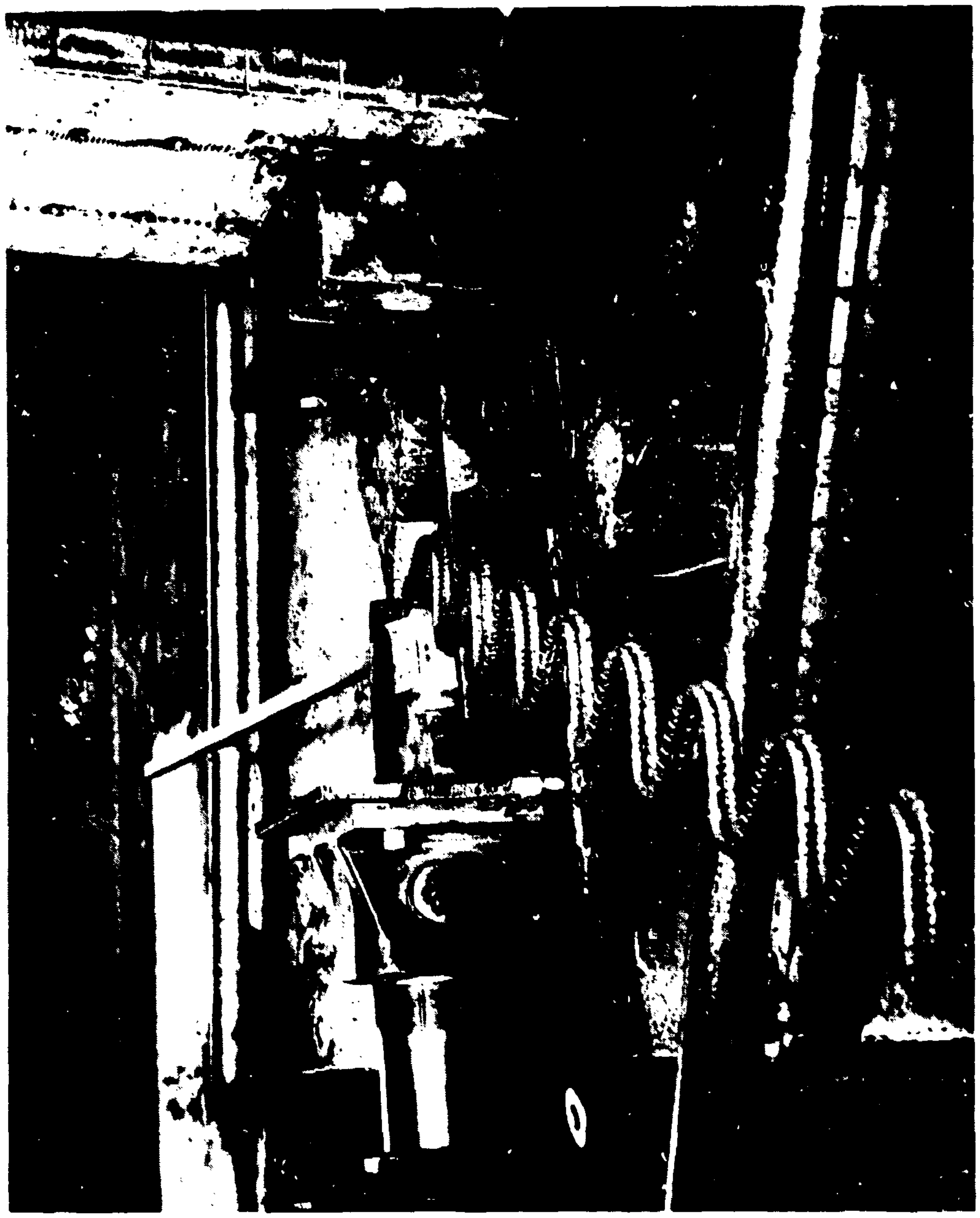


Fig. 12 SHOP FABRICATION OF LACING BARS

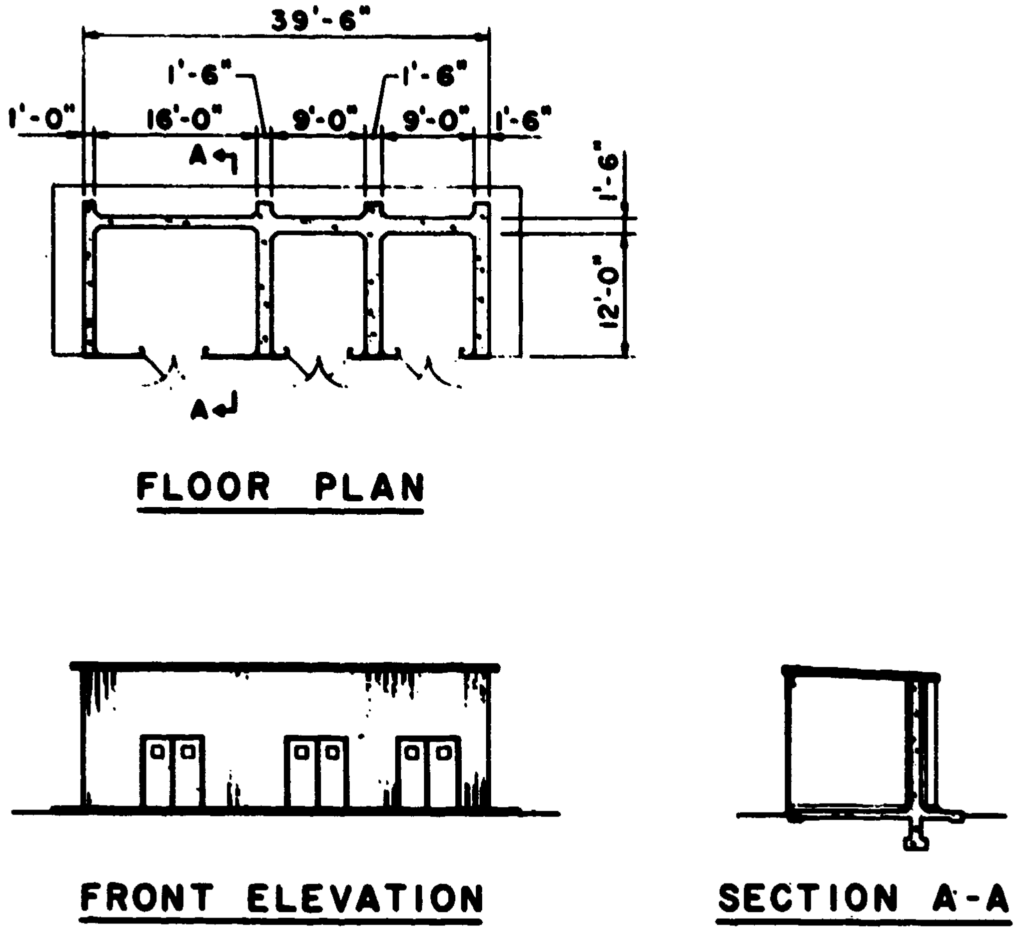


Fig. 13 VACUUM COLLECTOR BUILDING (HARDENED DESIGN)

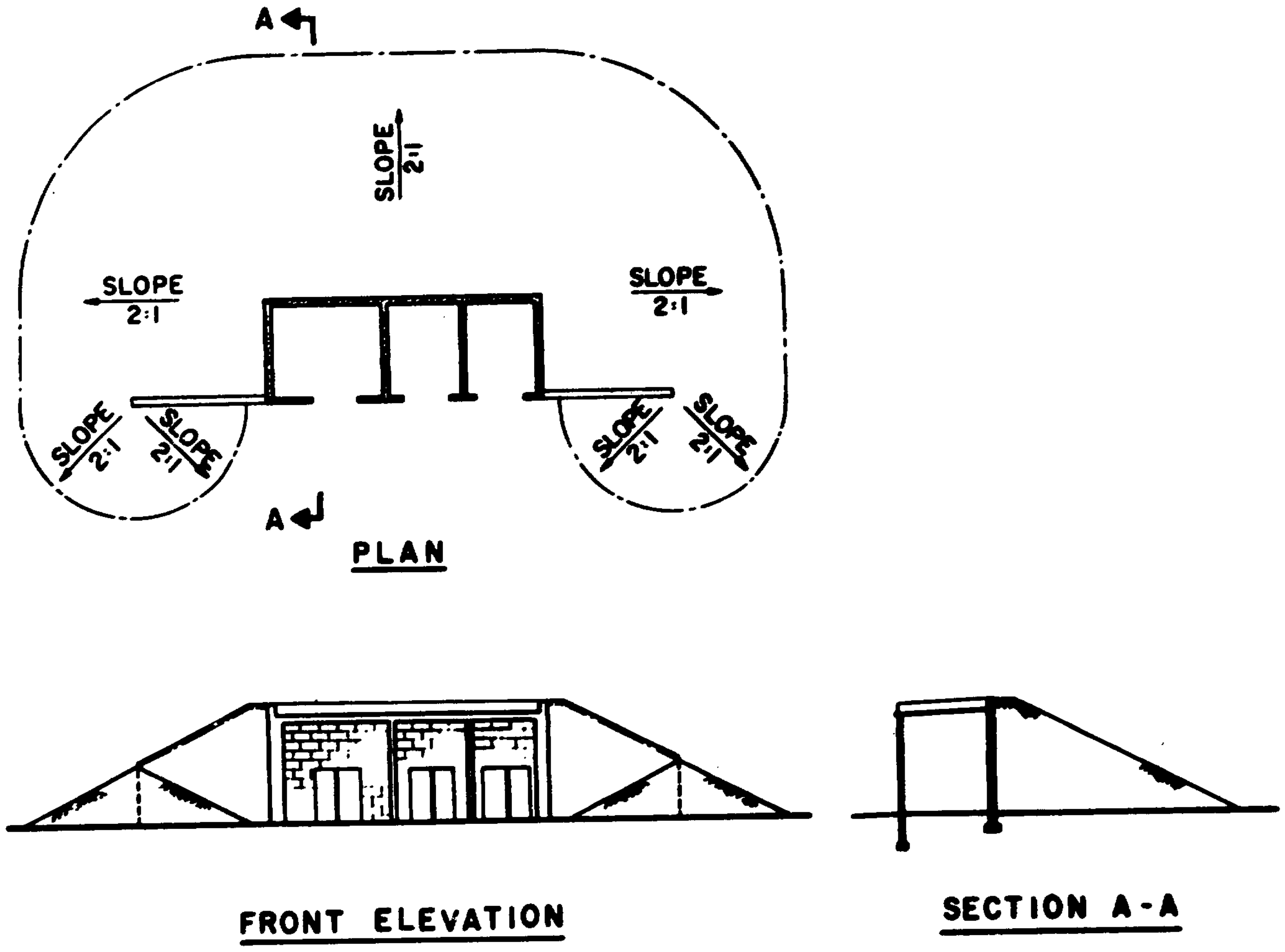


Fig. 14 VACUUM COLLECTOR BUILDING
(EARTH MOUNDED SCHEME)

MISSILE & ROCKET MOTOR TEST STRUCTURE

The Missile and Rocket Motor Test Structure contains a hold-down stand which is used to anchor the motor against accidental firing during continuity checks. The 7,000 pounds of solid propellent is assumed to have the explosive equivalency of an equal weight of TNT. The structure, as shown in Figure 15, is surrounded on three sides by earth revetments supported by conventionally-designed reinforced concrete retaining walls. The roof and front wall are frangible to vent an accidental detonation or firing of the motor being tested. The concrete hold-down block, acting in conjuction with the rear wall and earth fill, is designed to resist the sliding and overturning effects of a motor thrust of 125,000 pounds. A small earth mounded operators cubicle for remote control and TV monitoring is located adjacent to the test structure and separated by a distance equal to 1.25 $W^{1/3}$.

LUNCH ROOM-CHANGE HOUSE

Current standards for the locations of on-site ancillary structures, such as the Lunch Room-Change House, permit intraline distances as a minimum separation from structures containing explosives. The blast overpressures at the Lunch Room-Change House corresponding to these distances are shown in Table 1.

A study was made during the concept phase to determine the relative economics of providing protection compatible with the above blast parameters. Three approaches were considered, i.e., (1) conventional lightweight construction such as metal decking and siding shielded by means of barricades, (2) earth-mounded construction with lightweight roof and leeward wall, and (3) windowless hardened design.

Figure 16a shows the scheme associated with the conventional application of the barricade concept described in Reference 2. This scheme provides debris protection and reduced reflected pressure loadings for the blastward walls but does not significantly alter the pressure on the roof, side walls and leeward wall. Consequently the barricade alone would not provide consistent protection in this case. The

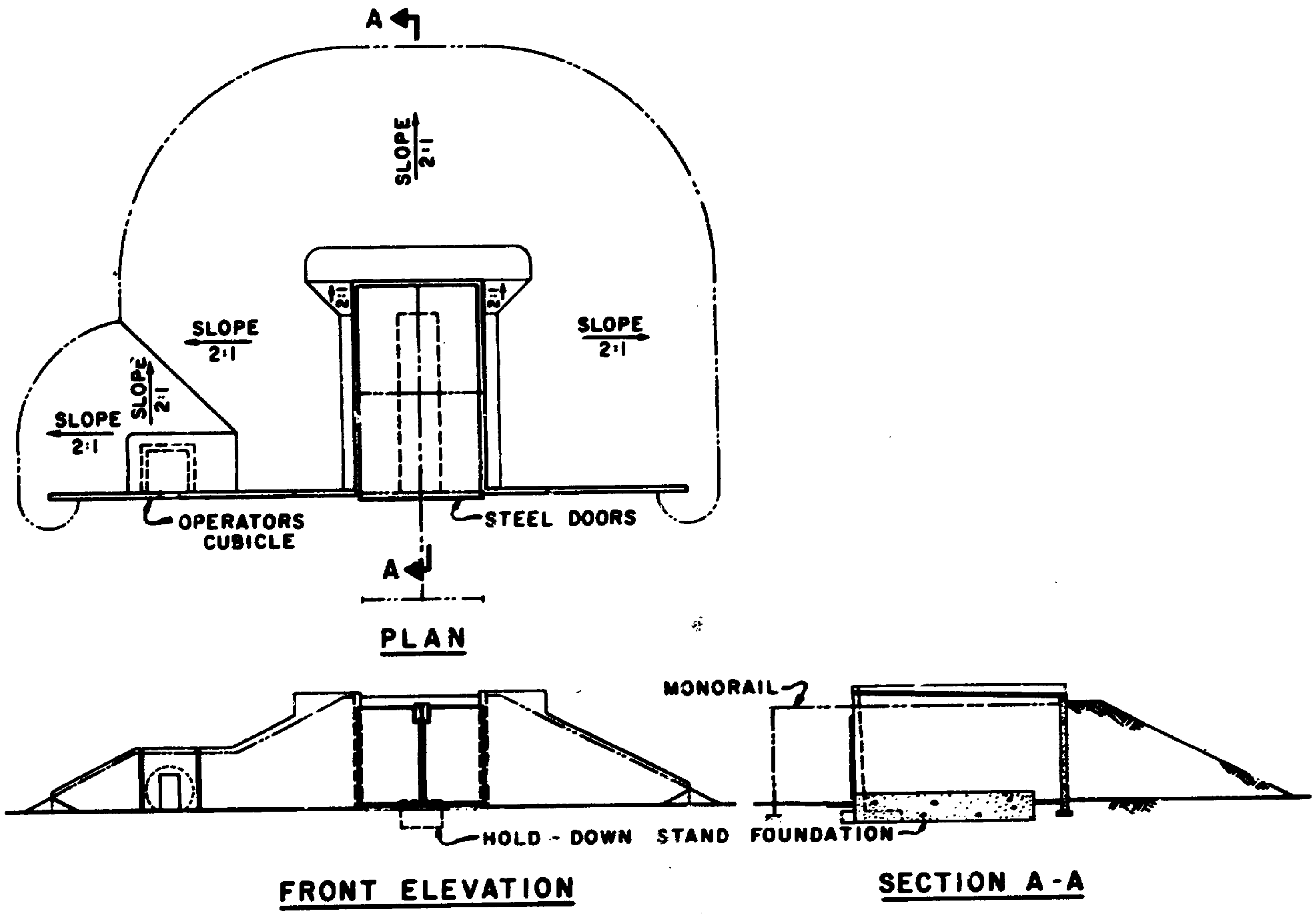


Fig. 15 MISSILE & ROCKET MOTOR HOLD-DOWN STAND

Table 1 - Blast Loadings at Lunch Room-Change House

Location of Detonation	Explosive Weight (pounds)	Intraline Distance (ft.)	Peak Side-On Pressure (psi)	Peak Reflected Pressures (psi)	Side-On Impulse (psi-sec. / sq. in.)	Reflected Impulse (psi-sec. / sq. in.)
Maintenance Bldg.						
Unbarricaded	25,000	530	3.5	7.7	0.16	0.35
Barricaded	25,000	265	12.0	32.0	0.30	0.80
Magazines (each)	5,000	150	6(12)	13(31)	0.09(0.18)	0.20(0.47)

NOTE: Values in parentheses are estimated values for unconfined surface burst. (Ref. 3)

provision of windows, particularly if they are substantial in size, would reduce the applied blast pressures on the shell of the structure by reducing the unbalanced loadings; however interior partitions, equipment and personnel would be exposed.

Figure 16 shows the scheme associated with an earth-mounded concept. This scheme provides improved protection at a reduced cost as compared to the barricaded scheme; however blast protection would still be lacking for the roof and leeward wall. Figure 17 illustrates the hardened design concept selected for the final design. Comparative cost studies determined that, aside from providing consistent protection, this concept was more economical than the other schemes considered. The walls are 12 inch concrete with minimum reinforcement and the roof is a 7.5 inch flat slab with reinforcement not exceeding 0.5 percent.

It should be noted that the Lunch Room-Change House, as designed, would be more than adequate at intraline distances corresponding to smaller charge weights and have a reduced structural capacity at intraline distances corresponding to charge weights greater than 25,000 pounds. The reason for this is that the recommended table of minimum intraline distances given in References 1 and 2 corresponds closely to a fixed incident overpressure level without apparent consideration of the related reflected overpressures or blast impulses.

CONSTRUCTION COSTS

The estimated average construction cost breakdown for the facility is shown in Table 2 based upon a regional cost index of unity.

Although the designs are far from comparable, it is of interest to compare the cost of this facility with the estimated costs which would have been incurred utilizing "Substantial Dividing Walls".

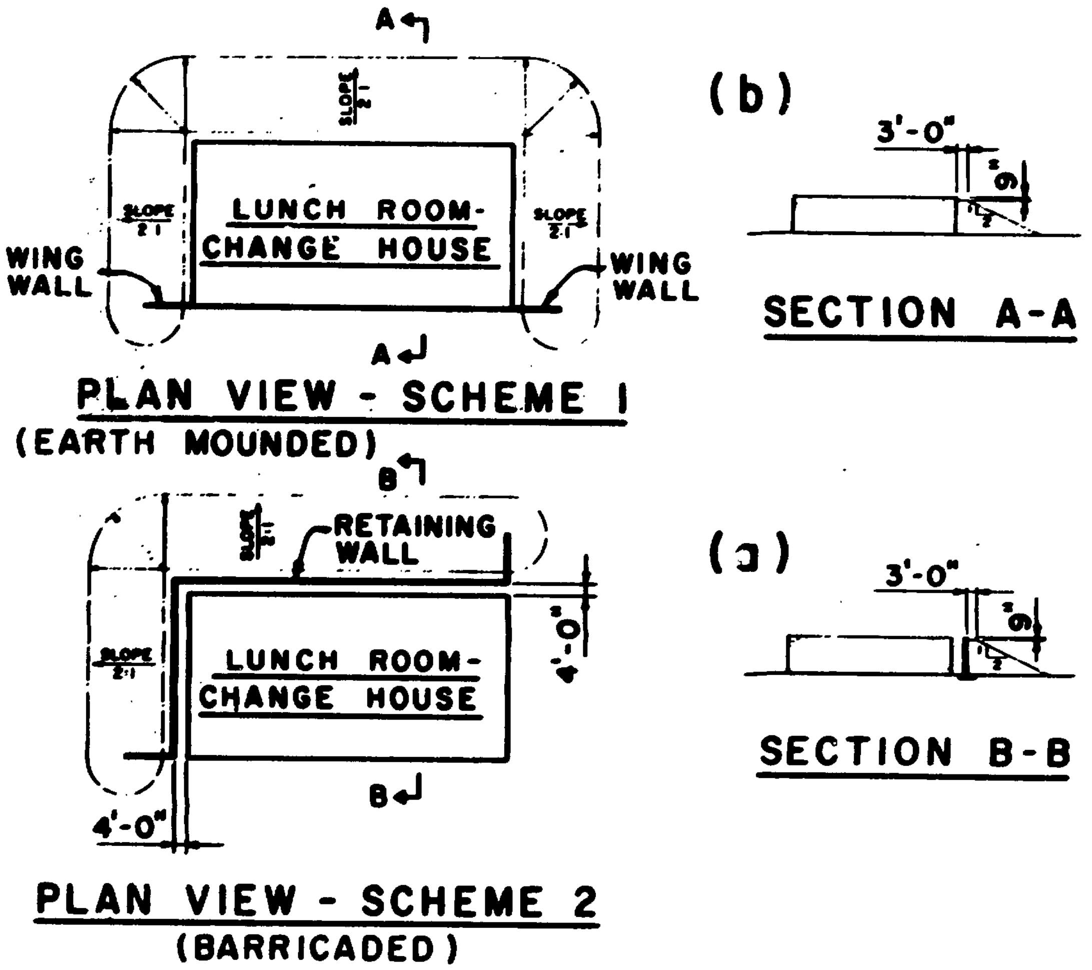


Fig. 16 LUNCH ROOM - CHANGE HOUSE
(BARRICADED & EARTH MOUNDED SCHEMES)

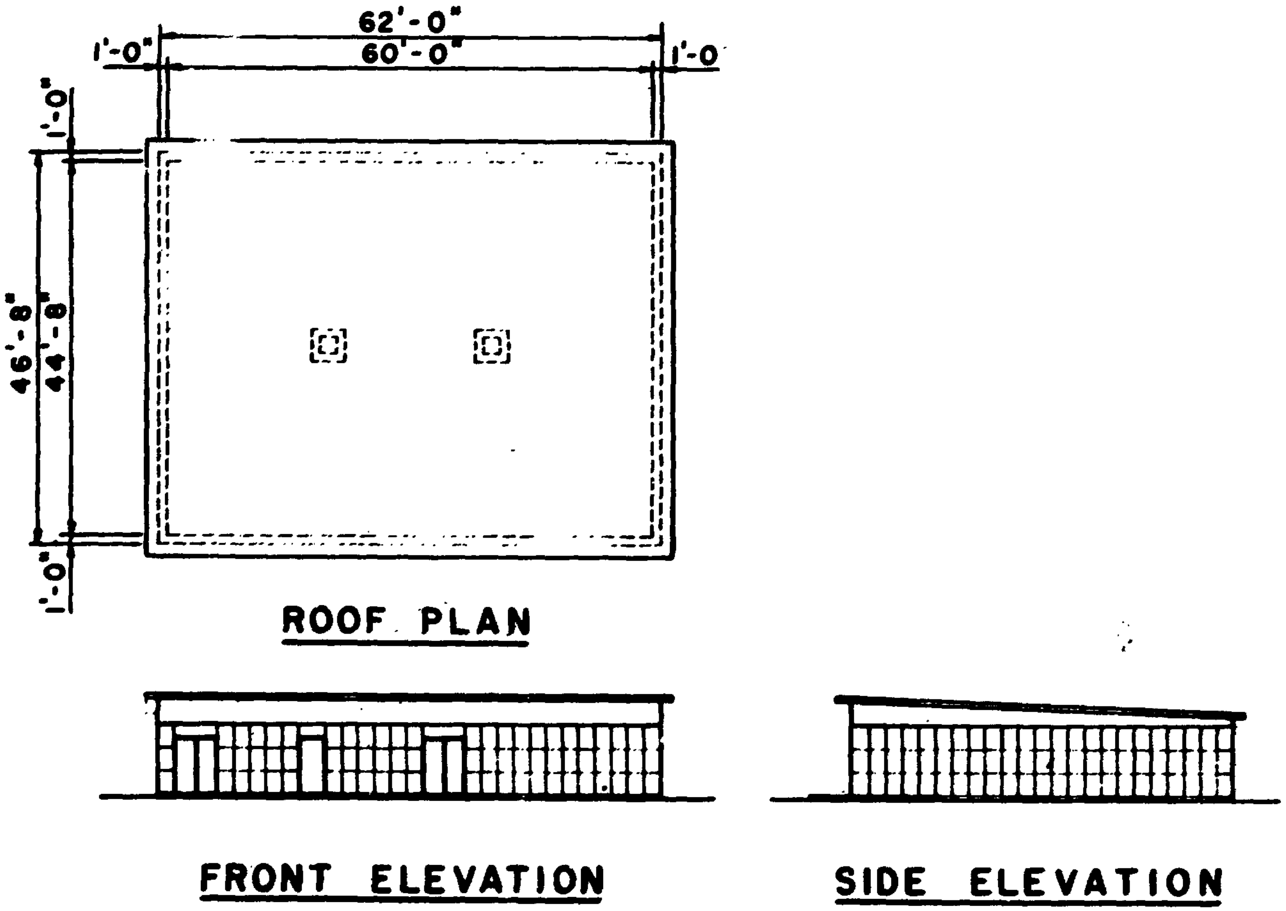


Fig. 17 LUNCH ROOM-CHANGE HOUSE
HARDENED DESIGN

TABLE 2

Ammunition Maintenance Facility - Average Construction Costs (Index = 1)

Item	Cost	Cost per Sq. Ft.	Area (Sq. Ft.)
Ammunition Bldg.			
Structural		$ 10.20	
Architectural		5.20	
Electrical-Mechanical		9.30	
Equipment *		4.80	
Sub Total	$749,000	29.50	25,400
Vacuum Collector Bldg.			
Building		53.60	
Equipment		24.30	
Sub Total	41,000	77.90	530
Flammable Stores Bldg.	6,700	16.90	400
Magazines (4)	32,000	21.00	1,530
Missle & Hold Down Stand			
Building		33.50	
Equipment		1.30	
Sub Total	26,000	34.80	740
Sentry House	2,500	61.00	40
Lunch & Change Bldg.			
Architectural		9.30	
Structural		9.60	
Electrical-Mechanical		11.30	
Sub Total	87,000	30.20	2,890
Support Facilities **	261,000		
Total	$1,205,000		

* Includes abrasive blast machine, overhead monorail system, paint spray booths, air compressors, power conveyor.

** Includes clearing and grubbing, unclassified excavation, concrete paving, bituminous access and interior roads, drainage, electrical service, sanitary system, water lines, seeding and sodding, fencing.

The following added costs are estimated for the current construction as compared to the "Substantial Dividing Wall" design for the Ammunition Maintenance Building:

increase in reinforced concrete work, including forms 65%

increase in building structural costs 50%

increase in total building cost 12%

increase in facility cost 6%

In many instances this added cost would be more than offset by the savings inherent in a design that prevents propagation of charges in adjacent cells. In such a design both onsite and offsite intraline distances may be determined on the basis of a single cell detonation resulting in possible substantial savings in site costs.

CLOSURE

The design and construction of the Ammunition Maintenance Facility described in this paper illustrates how the use of the present state of the art and new design techniques can be used to achieve a facility design providing protection substantially more compatible with the contained explosive hazard at little or no additional facility cost as compared to earlier designs. Moreover, if one considers the economics in the actual basis of facility cost per pound of explosive (reference 6), there is no doubt that his new approach will be substantially less expensive.

With the aid of future tests, knowledge should be extended to achieve refinements of current concepts and shed additional light on several areas of explosives - structure interaction where many uncertainties still exist. Hopefully, designs of tomorrow will continue to improve over designs of today.

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4. Blast Pressures and Impulse Loads for Use in the Design and Analysis of Explosive Storage and Manufacturing Facilities, N. Dobbs, E. Cohen and S. Weissman, Ammann & Whitney, New York, N.Y., Paper presented at the Conference on Prevention of and Protection Against Accidental Explosion of Munitions, Fuels, and Other Hazardous Mixtures, The New York Academy of Sciences, Division of Engineering New York, New York, October 1966.

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CASE STUDIES ON APPLICATION OF NEW DESIGN METHODS

FOR HIGH CAPACITY PROTECTIVE BARRIERS

BY

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In the following paper several case studies and designs are presented in which new design concepts for reinforced concrete developed under the Armed Services Explosive Safety Board (ASESB) Supporting Studies Program were applied to actual construction problems. These cases include design for new facilities and modification of existing facilities. The design capacities are established for different damage levels depending on the degree of protection required.

Case I - ASESB Simultaneity Dividing Wall

A request was made by the ASESB Hazard Work Group to design a protective wall which would preclude direct propagation between two 5,000 lbs charges placed 10 ft. from the wall. This test was designed to evaluate simultaneity aspects for separation of explosive charges.

Tests under other programs have resulted in propagation of explosion to acceptors through a standard 12 inch substantial dividing wall when donor quantities were as little as 400 lbs of HE. These propagating of explosives have occurred at time intervals of 3 to 20 msec after detonation of the donor charge. Hence, a separating (cantilever) wall was to be designed that would preclude the propagation of the second charge within a 20 msec period after which the second charge will be initiated separately.

A cantilever dividing wall was designed such that it would approach incipient failure condition when subjected to the blast output of 5000 lbs of TNT located at a distance of 10 ft. from the vertical surface of the wall. The incipient failure criteria for design was selected to insure that fragments from the wall would not result in propagation of the acceptor charge within the time interval specified. At this time, no predictions can be made as to the condition of the wall after the initiation of the second 5000 lbs charge, although wall failure is a likely possibility.

The test structure (Figure 1) consist of a 10 ft. high by 20 ft. wide by 4 ft. thick reinforced concrete cantilever wall This wall is constructed monolithic with and at the center of a reinforced concrete floor slab, the size of which is 34 ft. long, 20 ft. wide (width of the wall) and varies in thickness from 4 ft. 6 in. at the middle to 2 ft. 6 in. at both ends of the long dimension of the slab. The thickness of the slab is constant across its width at any particular section. Both the wall and the slab are heavily reinforced with flexural reinforcement. In addition, the flexural steel of the wall is tied with lacing reinforcement in the vertical and horizontal directions Also, to prevent large reflections of the blast pressures at the intersection of wall and floor slab, reinforced concrete haunches were constructed monolithically with both the wall and slab (a haunch is provided at each side of wall).

In this design, the capacity of the wall was calculated such that the potential energy developed in the wall was equivalent to the kinetic energy produced by the momentum resulting from the impact of the blast loads. This potential energy was based on a maximum deflection, at the top of the wall, corresponding to twelve degrees rotation at the plastic hinge formed in the wall at the top of the haunches. The analytical procedures used in this design utilized a single-degree-of-freedom system approach for solving Newton's Laws of motion.

It should be noted, that because the dividing wall was a test structure and, therefore, having an individual cell arrangement, the thickness of the floor slab below the wall was governed by the overturn of the entire structure. In those cases where a multi-cell arrangement would exist, the thickness of the floor could be reduced to that which exists at the floor slab edges.

Several interesting construction techniques were utilized in this design. First, the concrete cover over the reinforcement was held to a minimum (lacing placed flush with wall surface) to reduce the amount of concrete spalling. Also, lacing reinforcement was placed in two directions (Horizontal and vertical). The vertical lacing provided the capacity to resist the high shear produced at the wall base in addition to fully developing both the positive and negative flexural reinforcement (vertical steel). On the other hand, the horizontal lacing was incorporated to distribute the high blast loads, occuring adjacent to the charge, to other sections of the wall where lower blast intensities occur.

The dividing wall is now in process of being constructed and at present it is anticipated that the test will take place in the latter part of the year 1967.

SIMULTANEITY TEST

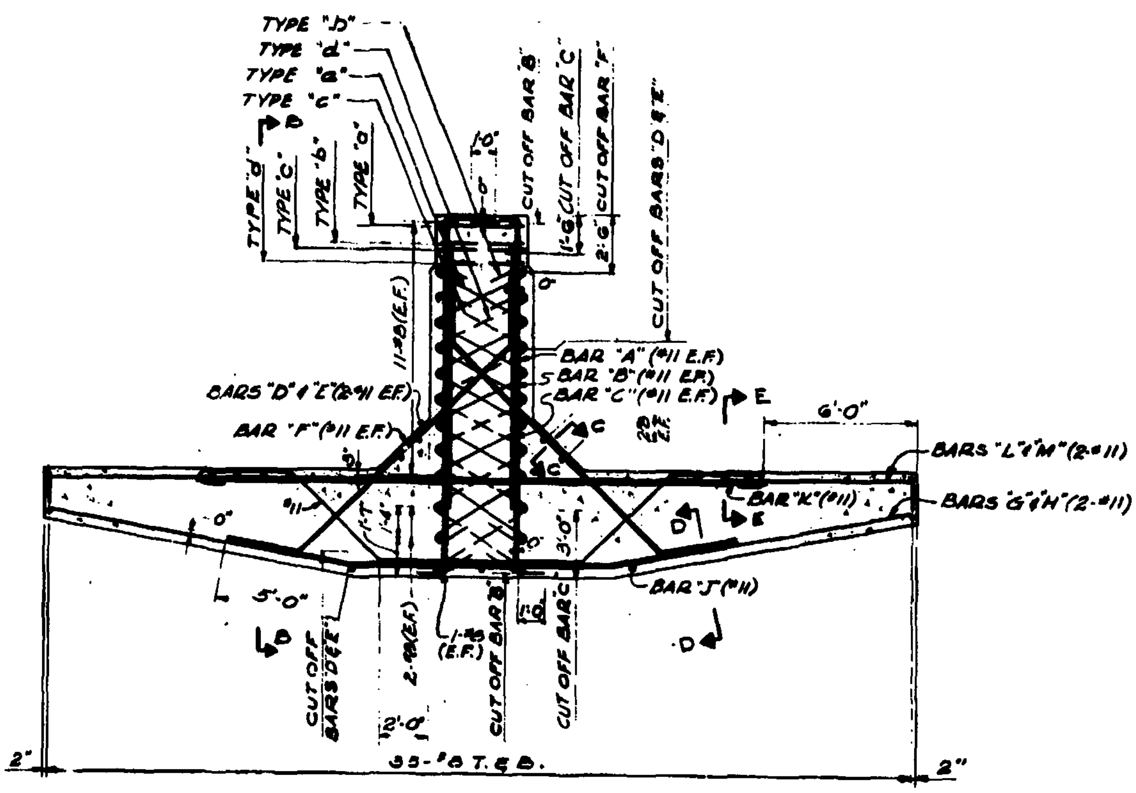


Figure 1

Case II - Assistance in Preparation of Guided Missile - Heavy

Rocket Facility Design

A request was made by the Office Chief of Engineers to render assistance in designing protective walls for Guided Missile - Heavy Rocket Facility.

The facility (Figure 2) consists of a rectangular structure with a floor area equal to approximately 6,000 ft. The building is separated into six basic areas each of which is separated by transverse reinforced concrete dividing wall. The floor slab and interior walls are reinforced concrete while the roof is made of light weight steel joints and metal decking and the exterior walls are made from off the shelf insulated metal panels to minimize blast reflections.

The three right hand sections of the building are explosive cells used for maintenance of the rockets. Each cell is 25 ft. wide by 52 ft. long (width of the building). As mentioned above the roof and the two longitudinal walls of each cell are frangible, while the concrete walls separating two adjoining cells are designed to prevent propagation of detonation into an adjacent cell with equivalent weight of high explosives (TNT) charge equal to 7,500 lbs. The charge is assumed to be located midway between two adjacent walls, the clear separation being 25 ft.

To prevent propagation it was suggested that two criteria may be established:

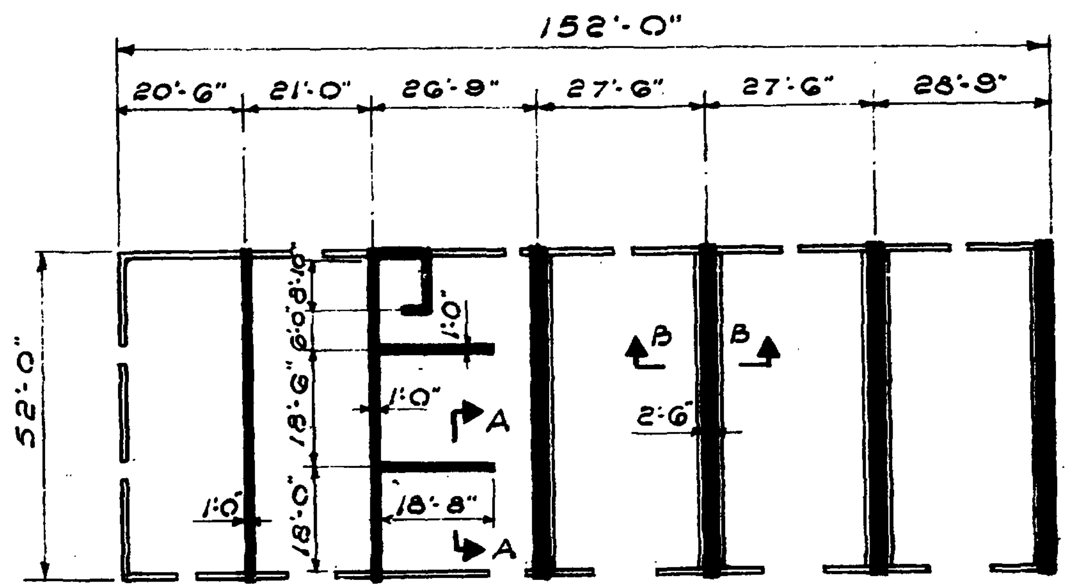
a. To design the dividing wall for incipient failure, where only small amounts of spalled fragments with low velocities will be produced.

b. To permit wall failure with controlled fragment velocities.

Of the two, the incipient failure design was the more reliable, because at present, only a minimum amount of information is available as to the sensitivity of acceptor charges to fragment impact, but this design is much more expensive.

Calculations were performed to determine blast output resulting from a detonation of 7,500 lbs of TNT equivalent located at 12.5 ft. from a dividing wall and required impulse load capacities for reinforced concrete walls to resist the above blast loads.

GUIDED MISSILE - HEAVY ROCKET FACILITY



FLOOR PLAN
SCALE: 1/32" = 1'-0"

Figure 2

The results are as follows:

a. Average unit impulse load acting on the wall - 7,500 lbs msec/in^2.

b. Depending on the degree of damage allowable the required unit impulse capacity for cantilever wall (52 ft. long x 12 ft. high) for:

(1) Scheme I - (Incipient failure) - 7,500 lbs msec/in^2.

(2) Scheme II - (Resulting wall fragment velocities of 100 ft/sec.) - 2,940 lbs msec/in^2.

(3) Scheme III - (Resulting wall fragment velocities of 300 ft/sec.) - 980 lbs msec/in^2.

c. The above impulse capacities are based on recommended wall configurations which are as follows:

(1) Scheme I - 4 ft. 6 in. thick wall (3 ft x 3 ft haunches)

(2) Scheme II - 2 ft. 6 in. thick wall (2 ft x 2 ft haunches)

(3) Scheme III - 1 ft. 4 in. thick wall (1 ft x 1 ft haunches)

The above mentioned impulse loads and wall thicknesses were based on new design procedures for reinforced concrete wall utilizing lacing reinforcement.

In addition, recommendations were made concerning test room (Figure 2) where a maximum of 50 lbs of HE would be handled at any one time. It was suggested that dividing walls in the testing room could be reduced to 12 inch thick walls providing laced reinforcement was incorporated in wall design to fully develop flexural reinforcement. Previous design indicated that an 18 inch thick wall with larger amount of flexural reinforcement was required. It was also stressed that the additional cost of fabrication and placing the lacing reinforcement should be offset by the reduction of wall thickness and flexural reinforcement as originally designed.

It was further recommended that the reinforced concrete walls and roof slabs of the above recommended type (12 inch thick with lacing) replace the frangible portion of personnel inclosures to provide full

protection against explosion in the testing room and also a higher degree of protection from the effects of an explosion of 7,500 lbs in any of the missile cells.

Since the design for incipient failure condition of the missile storage cells proved to be expensive (see Ref 1 for cost evaluation) it was recommended that Case II (wall failure with resulting fragment velocities not exceeding 100 ft/sec.) be utilized in the facility design. Our previous sensitivity tests with bare charges of Comp. B indicated that propagation of detonation will not occur at velocities of less than 300 ft/sec. using 70 lbs rubble.

Upon the final selection of Scheme II, it was requested that a redesign of the wall be accomplished utilizing 1 ft. x 1 ft. haunches (Figure 3). This reduction in the size of the haunches resulted in a slight increase of the flexural and lacing reinforcement.

The majority of our recommendations were accepted at the concept conference in Washington, D.C. while others are under consideration.

Case III- Study of Cubicle Explosive Limits

A request was made to review the blast resistance capabilities of a building used for loading ammunition items and to evaluate the protection afforded to personnel in areas of the building adjacent to the test cubicle.

The structure (Figure 4) has overall dimensions of 60 ft. long by 35 ft. wide. The interior of the structure is divided into three main sections, namely; (1) operational (or personnel) (2) test cubicle and (3) passageway between the test cubicle and operational room.

The test cell (Figure 5) is separated from the operational room by an "L" shaped concrete blast wall. The lower and upper portions of the wall are 3 ft. and 1 ft. thick, respectively. The passageway is separated from the test cell and operational room by concrete block walls.

The analysis of structure revealed the following:

a. For complete protection of personnel operating area, blast resulting from less than 15 lbs. of HE can be tolerated. In order to limit potential blast damage to tolerable level of personnel protection the amount of explosive should be kept to somewhat less than 15 lbs at any one time.

b. The critical section of the overall structure is the frangible roof which will collapse from explosions resulting from 15 lbs of HE.

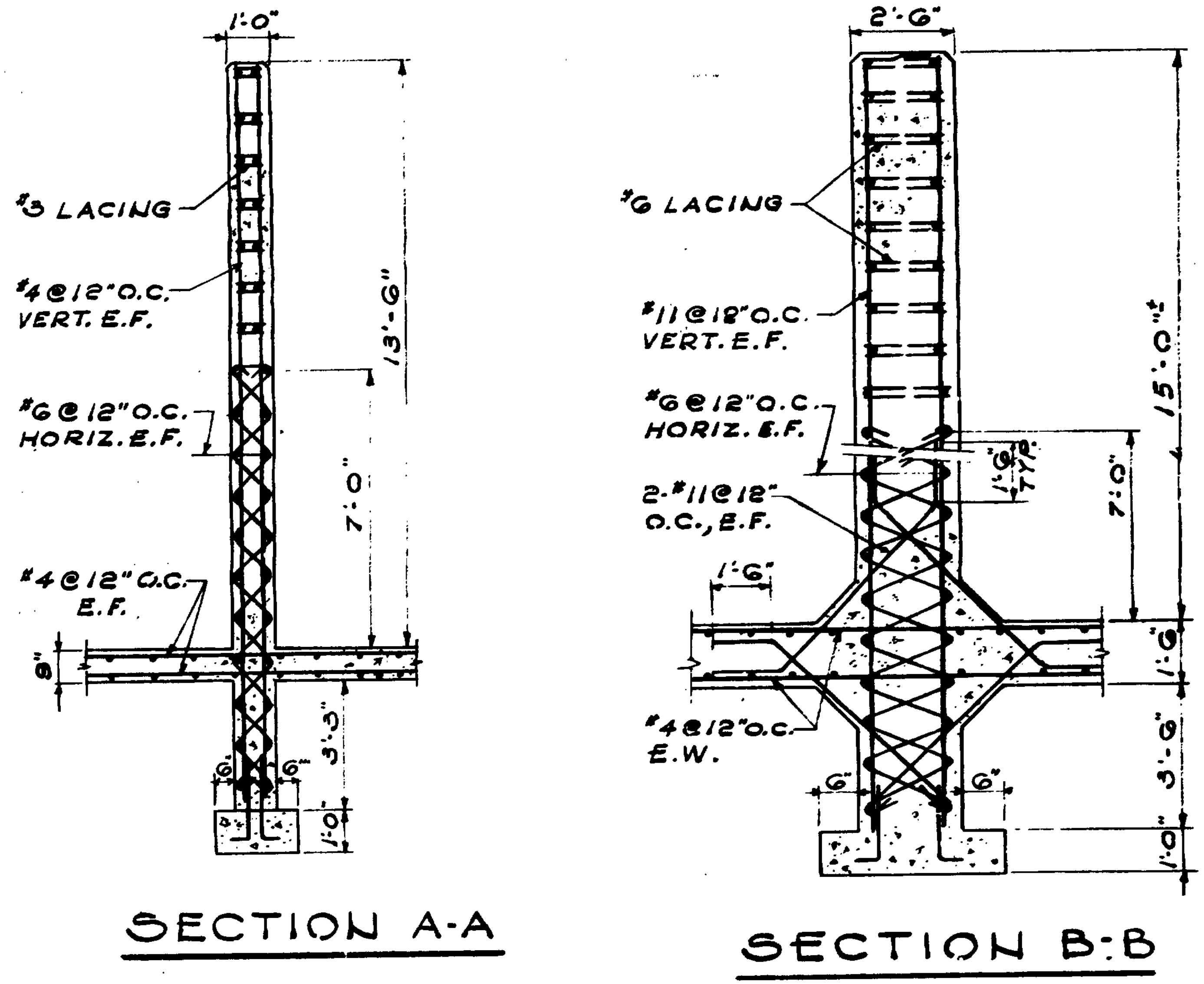
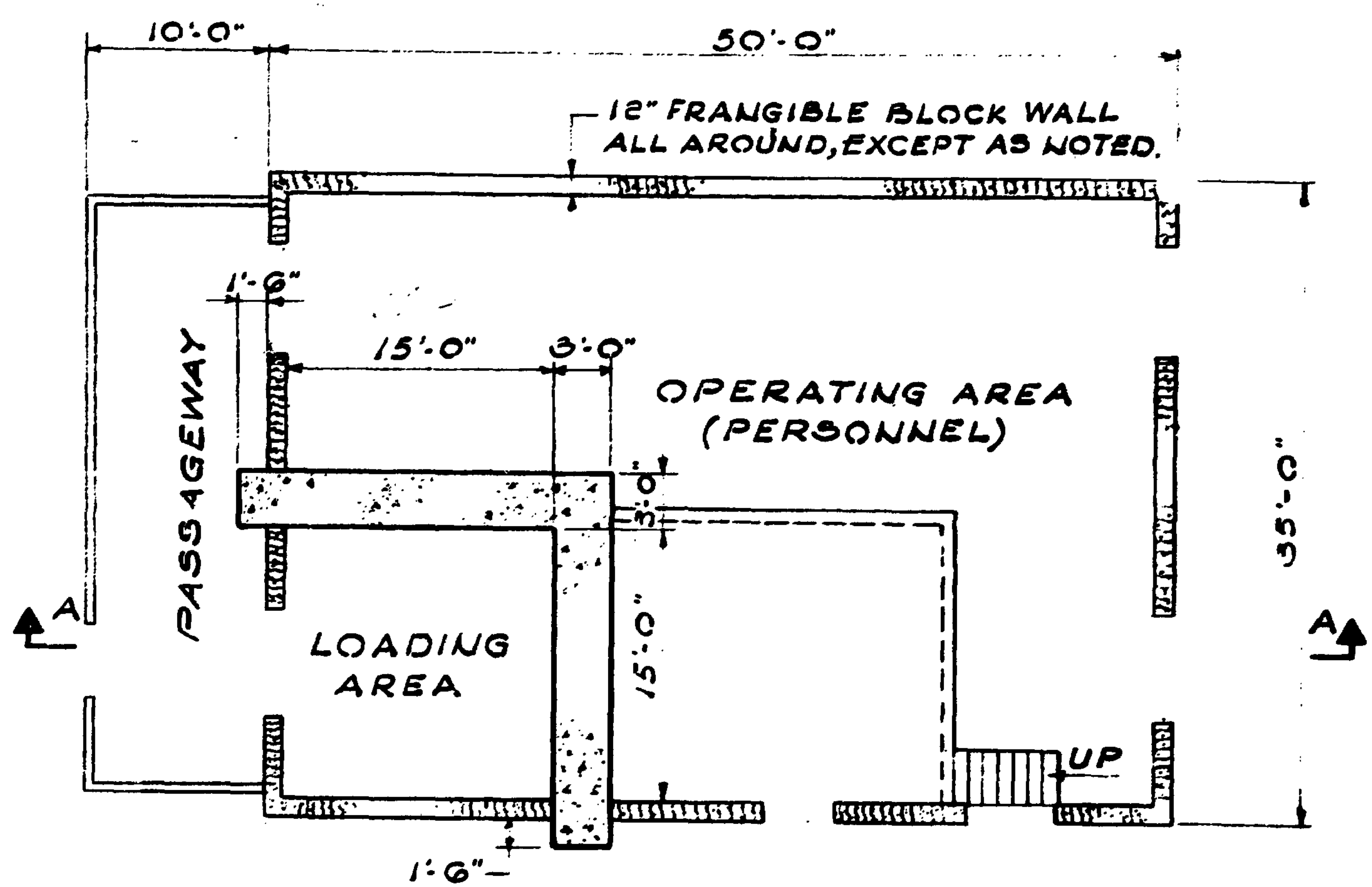

1'-0"
#3 LACING
#4 @ 12" O.C. VERT. E.F.
#6 @ 12" O.C. HORIZ. E.F.
#4 @ 12" O.C. E.F.
9"
13'-6"
7'-0"
3'-3"
6"
6"
1'-0"
SECTION A-A
2'-6"
#6 LACING
#11 @ 12" O.C. VERT. E.F.
#6 @ 12" O.C. HORIZ. E.F.
2-#11 @ 12" O.C., E.F.
1'-6"
#4 @ 12" O.C. E.W.
1'-6" TYP.
15'-0"±
7'-0"
1'-6"
3'-6"
6"
6"
1'-0"
SECTION B-B

Figure 3

AMMUNITION LOADING BUILDING

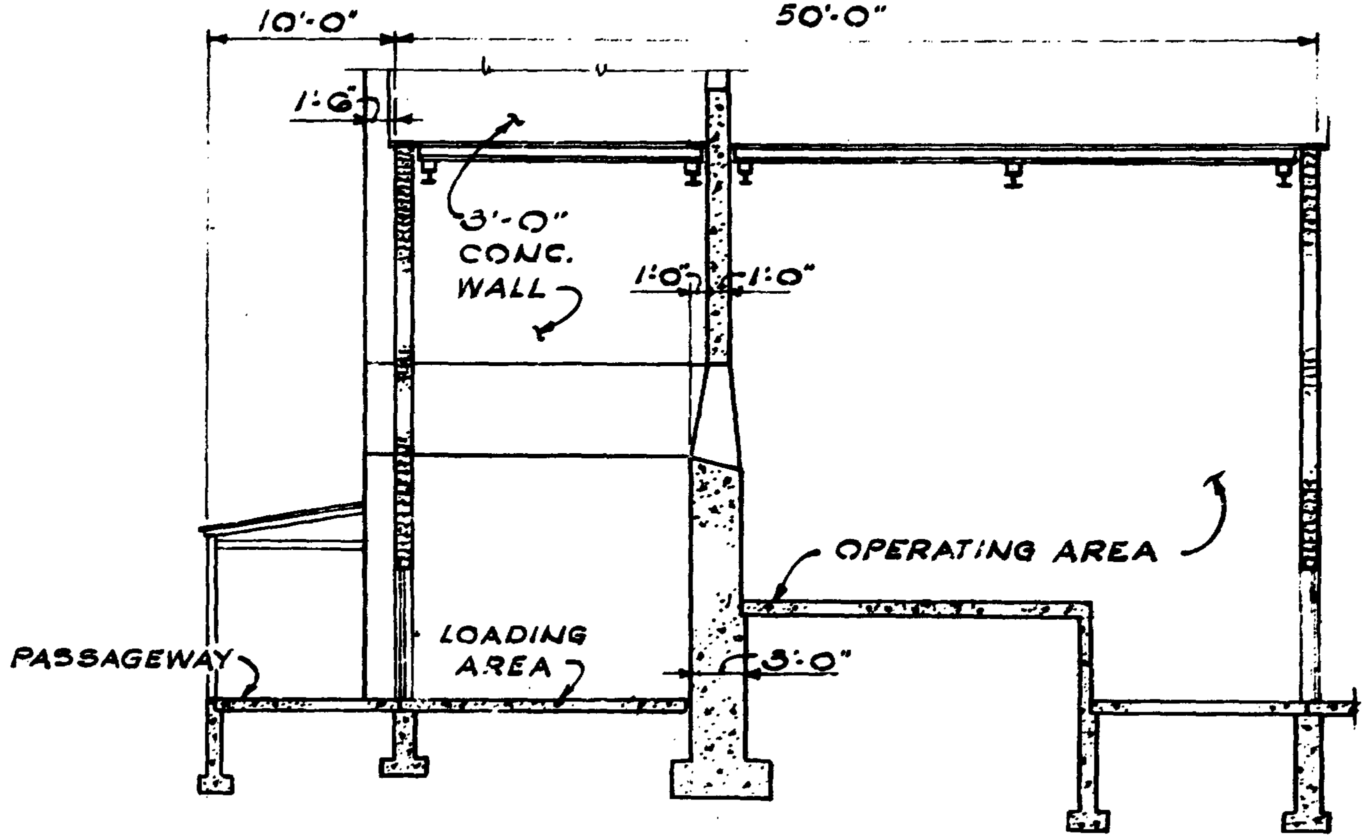


FLOOR PLAN

SCALE: 3/32" = 1'-0"

Figure 4

AMMUNITION LOADING BUILDING



SECTION A-A

SCALE: $\frac{3}{32}'' = 1'$-0"

Figure 5

c. The overturning analysis of the blast walls (3 ft. thick walls separating the loading area from personnel operating area) indicated that large permanent rotations will occur without producing overturning at the 100 lbs detonation level. Consequently, considerable damage to the roof in the operating area will occur due to excessive deflections of the two reinforced concrete walls.

d. The flexural analysis (bending and shearing) of the blast walls revealed that the threshold conditions for incipient failure will result from detonation of 100 lbs of cyclotol in the loading area.

e. On the other hand blast resulting from only 20 lbs HE detonation will destroy the outside walls of the test cubicle resulting in formation of fragments and spillage of overpressure. The overpressure, might damage the exterior block wall enclosing personnel area.

This cursory analysis of a typical HE operating building indicates the shortcoming of the present design. On one hand the blast walls could withstand the blast resulting from detonation of about 100 lbs of HE, on the other hand other components of the building (roof and sidewalls) would be ineffective in preventing injury to personnel resulting from detonation of less than 20 lbs of HE.

The following recommendations were offered to correct some deficiencies as outlined above:

Without major modifications in roof construction there is little that can be done to increase the hardening of the existing structure to provide the necessary protection for personnel in the operational area. On the other hand for new construction - as was anticipated for increased production of the highly critical HE items - the building should be constructed of reinforced concrete for all exterior surfaces and that includes roof and sidewalls (except for the blow-out sidewalls and roof of the blast cubicle). To reduce the mass of the fragments, which might result from HO detonation, the use of metal siding in place of concrete blocks for frangible section of the loading cell was recommended. Finally, a test plan to verify the analytical conclusions on a model scale or even component tests similar to our slab test series were recommended.

It is expected that the forthcoming Safety Design Manual which is being prepared under the Safety Design Criteria Program will be helpful in solving many design, construction and siting problems encountered in the storage and processing of explosive materials.

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ONE-HALF DAY SPECIALIST SESSION

"ELECTROSTATIC AND ELECTROMAGNETIC HAZARDS"

Session Chairman:

Mr. L. M. Jercinovic

Sandia Corporation

Albuquerque, N. M.

Papers Presented Were By:

Messrs. J. P. Burger & D. L. Rost, Sandia Corp

Mr. Dan Waxler, Picatinny Arsenal, Dover, NJ

Mr. C. M. Cormack, Naval Air Systems Command Hq, Wash, DC

Mr. E. E. Vanlandingham, NASA Langley Research Center, Va. &
Mr. E. E. Hannum, Franklin Institute Research Labs, Phila., Pa.

Mr. C. T. Davey, Franklin Institute Research Labs, Phila., Pa.

Mr. Marx Brook, New Mexico Institute of Mining & Technology

PRELIMINARY REPORT OF THE INITIATION OF VARIOUS TYPES OF ELECTROEXPLOSIVE DEVICES BY INDUCED LIGHTNING

by

Joseph P. Burger

and

D. L. Rost

ABSTRACT

During the summer of 1966, the following experimental work was performed at the Langmuir Upper Atmosphere Research Laboratory of the New Mexico Institute of Mining and Technology, located some 30 miles south, southwest of Socorro at an altitude of 10,640 feet.

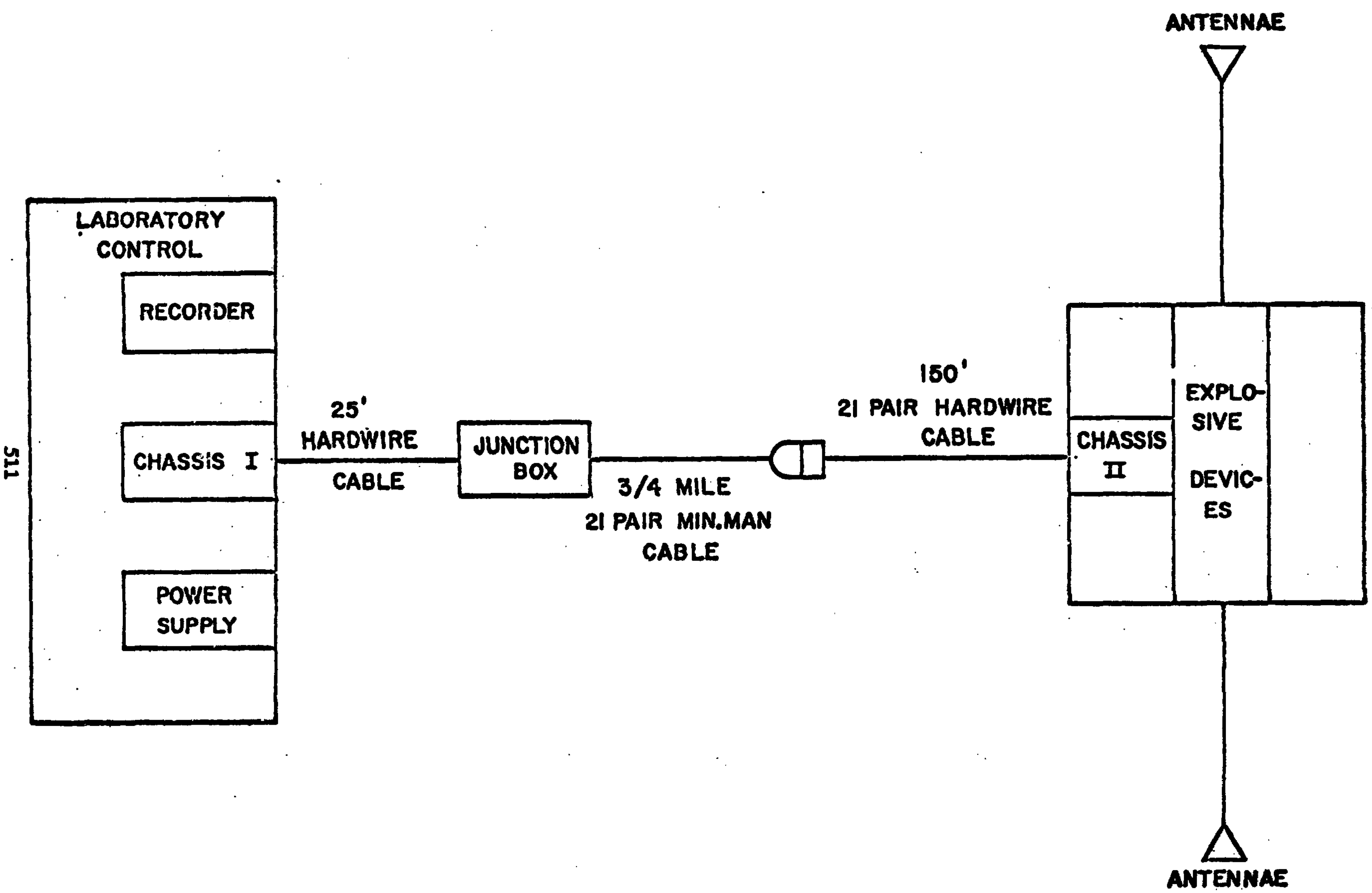
A variety of types of electroexplosive devices used by Sandia were placed in a field location approximately 3/4 mile from the laboratory. These devices were laid out with various types of typical lead configurations. These devices were then connected by hard wire to a 21-pair cable extending from the field location to the laboratory where they were terminated at a CEC recorder. Each device was connected to a film switch so that, if the atmospheric electrical activity induced a firing current on the device leads, the device would become initiated, the film switch would be opened and the time code would be generated on the recorder. Ultimately, these time code signals will be correlated with other data which have been collected by the laboratory on atmospheric conditions and a correlation made between those conditions and the device that was initiated.

INTRODUCTION

For years, there has been much concern by the users of electroexplosive devices about the effect of static potential gradient on EED's. In order to correlate phenomena associated with electrical activity with the use of electroexplosive devices in field of operations, a study was originated late in the summer of 1965 with members of the staff of the New Mexico Institute of Mining and Technology. The work at that time was on a short-term basis, using unsophisticated techniques and with very limited results. A more scientific approach was begun this spring and a contract negotiated with NMIMT to carry out these experiments. Twenty-six devices were initiated by lightning during the months of July and August, when eight events occurred. The events, date, time, and devices initiated are listed in Table I.

In this memorandum, we are presenting a description of the apparatus and instrumentation involved, the description and firing characteristics of the electroexplosive devices which were initiated, the antenna configurations associated with each device, the weather conditions, and the electrical activity at the time of each event. Figure 1 shows the systematic arrangement of the project at the Langmuir Upper Atmosphere Research Laboratory.

Figure 1



ANTENNAE
LABORATORY CONTROL
RECORDER
CHASSIS I
POWER SUPPLY
25' HARDWIRE CABLE
JUNCTION BOX
3/4 MILE 21 PAIR MIN.MAN CABLE
150' 21 PAIR HARDWIRE CABLE
CHASSIS II
EXPLOSIVE DEVICES
ANTENNAE

TABLE I

Initiation of Various Types of Electroexplosive Devices by Induced Lightning at the Langmuir Upper Atmosphere Laboratory

Event	Date	Time	Devices
I	July 7-14, 1966	Not recorded	A
II	July 14, 1966	12:30 to 1:15 PM	B C D E F
III	July 29, 1966	17:32:33	D
IV	August 4, 1966	12:27:57	G H E F A
V	August 4, 1966	12:35:26	C I
VI	August 8, 1966	14:20:42	J K D E C G L
VII	August 9, 1966	14:22:40	M
VIII	August 26, 1966	14:10:34	N

ELECTRIC FIELD METER

The electric field meter amplifier range controls the sensitivity of the electric field meter. When there is a large amount of electrical activity in the immediate area, then the meter range will be set at a large value on the control switch so any recorded values of the electric field will remain on scale. A value of 30 k on the control indicates that the meter is recording potential differences on the order of 30,000 volts/meter. A value of 1 k would mean potential differences on the order of 1000 volt/meter and 0.3 k, 300 volt/meter. A small value such as 0.3 k can be used in recording data on an electrical storm that is at a substantial distance from the field meter.

RECORDING OSCILLOGRAPH

The recording oscillograph is an instrument capable of recording any static or dynamic phenomenon which is convertible to an analog voltage. Sensing these phenomena is usually accomplished with low voltage output transducers, which translate mechanical variations into electrical impulses.

Electrical impulses produced by transducers may be fed into an amplifier or bridge balance where the signal is conditioned before being introduced into the oscillograph. The signal is then applied to a highly sensitive galvanometer in the oscillograph. Light from an illuminator is reflected by the galvanometer mirror through a simple optical system which produces a spot of light on a moving strip of photographic material.

By using various combinations of light intensity and record speed, clear, legible records are obtainable over a wide range of applications which necessarily vary as the job requirements change.

The Model 5-124 oscillograph, used in our experimental work, was a multi-channel, portable, ground environment, direct-recording, photographic-type instrument. It uses a 7-inch-wide printout recording paper, and provides up to 18 individual channels of data on visible records without chemical processing.

In our experimental work, 17 electroexplosive devices and a time code signal were connected to the above described recording system.

THE EXPLOSIVE CONTAINER

The 60 x 60 x 24 inch container for the electroexplosive devices was made of 3/4 inch reinforced plywood, lined with 4 inches of polyurethane foam. Inside the large container were five boxes made of 1/2 inch plywood. Each of these boxes had compartments so that there would be no propagation and were tightly fitted into the larger box. The 1/2 inch plywood boxes were fitted with lucite covers to provide easy visual monitoring of the EED with a minimum of exposure. Each compartment was large enough to hold a device without crowding.

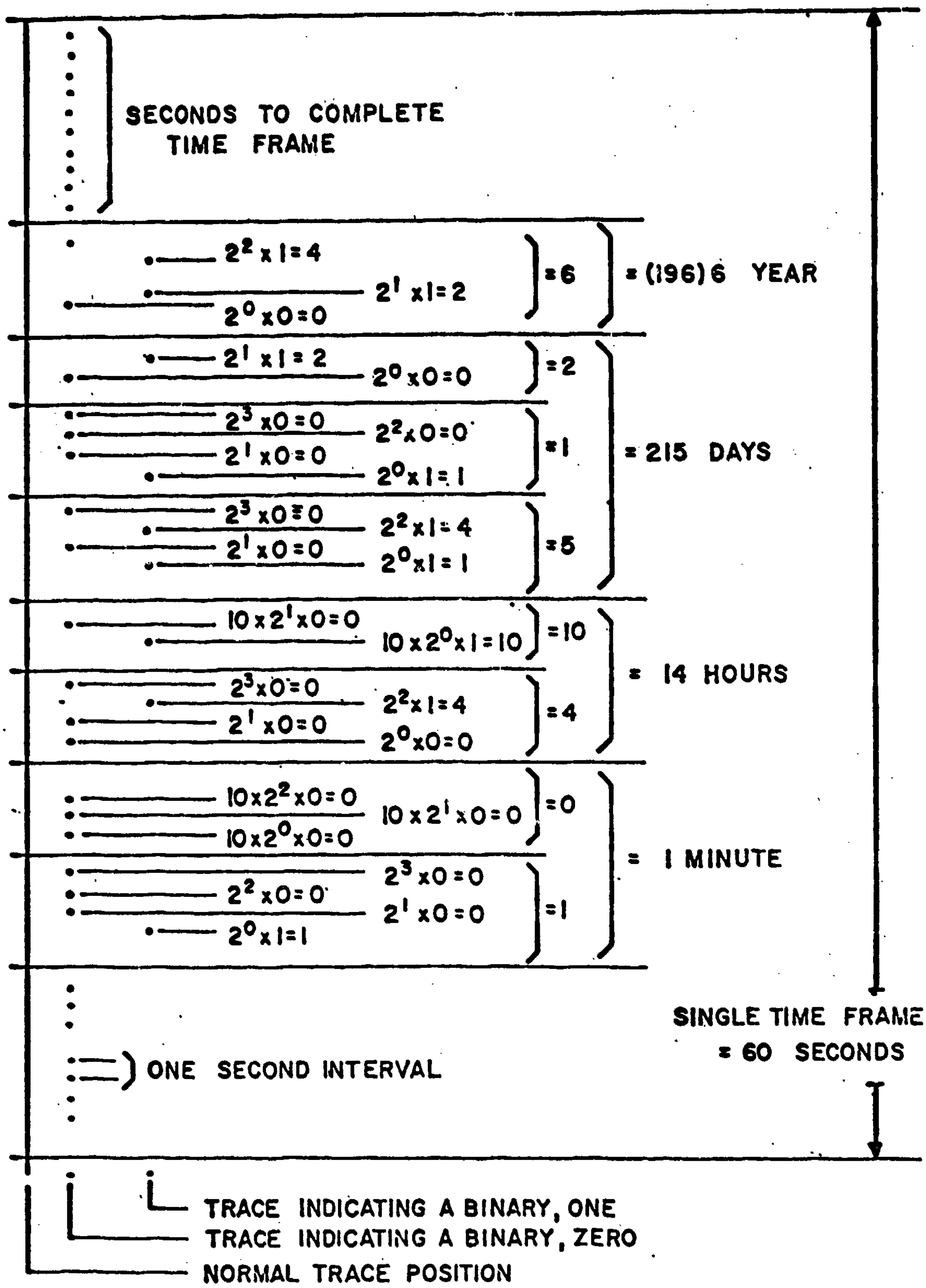
HYPERION TIME CODE

The trace lines are numbered from the left to the right, beginning with one and ending with 18. Trace Line Number 18 is connected with the signal from the slow time code. The deflections of Trace Line 18 can be interpreted to give: the year, day, minute, and second within each time frame of 60 seconds or about each 4 inches of the recording paper. This time code gives the time signals in the binary decimal system. An example of how this code is interpreted is shown in Figure 2.

FIGURE 2

HYPERION TIME CODE

TIME FRAME FOR THE FIRST MINUTE OF THE
14TH HOUR OF THE 215TH DAY OF THE YEAR 1966



ADDITIONAL INSTRUMENTATION

Other instrumentation records the temperature of the laboratory, the forest, and the soil. The radioactive precipitator indicates the amount of beta and gamma radiation as well as alpha particles in the atmosphere. The precipitation and atmospheric pressure is recorded by means of a solar radiometer. The static gradient (electrical field) in kilovolts is measured as well as the velocity and direction of the wind.

ELECTRICAL SCHEMATICS

(Figures 3, 4, 5)

Figure 3

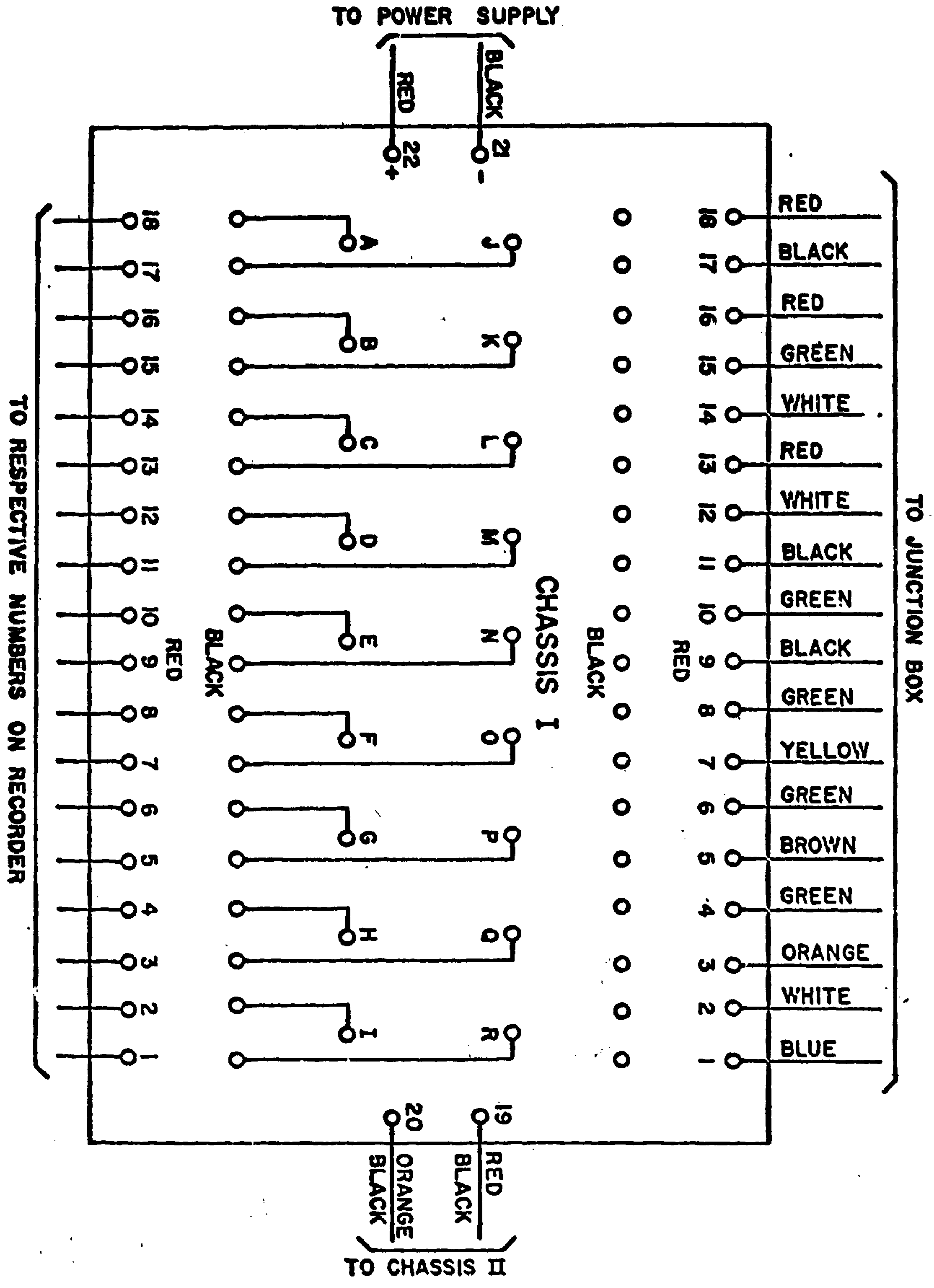

TO POWER SUPPLY
RED
BLACK
22 +
21 -
CHASSIS I
TO RESPECTIVE NUMBERS ON RECORDER
TO JUNCTION BOX
RED
BLACK
RED
GREEN
WHITE
RED
WHITE
BLACK
GREEN
BLACK
GREEN
YELLOW
GREEN
BROWN
GREEN
ORANGE
WHITE
BLUE
20
19
ORANGE
BLACK
RED
BLACK
TO CHASSIS II

Figure 4

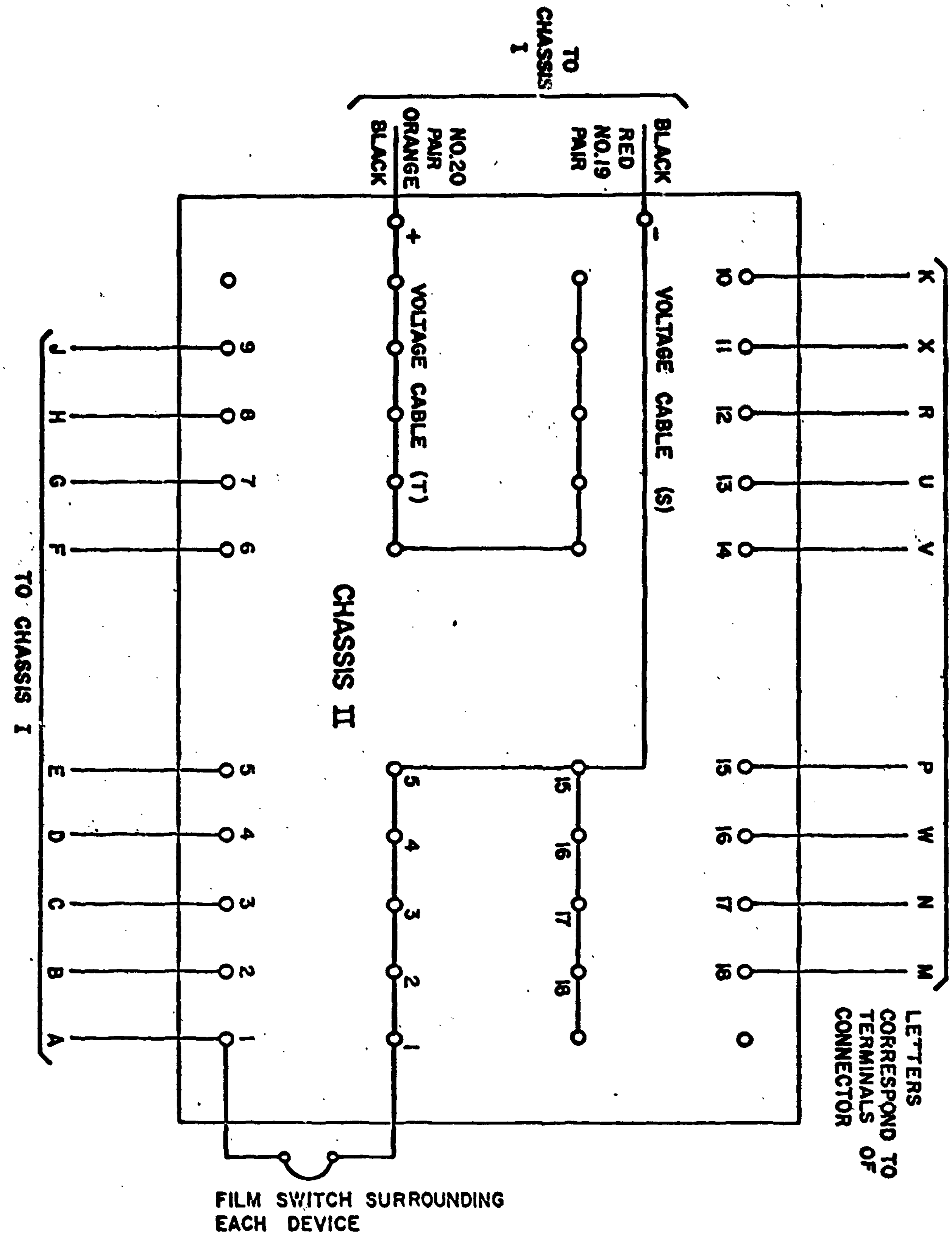
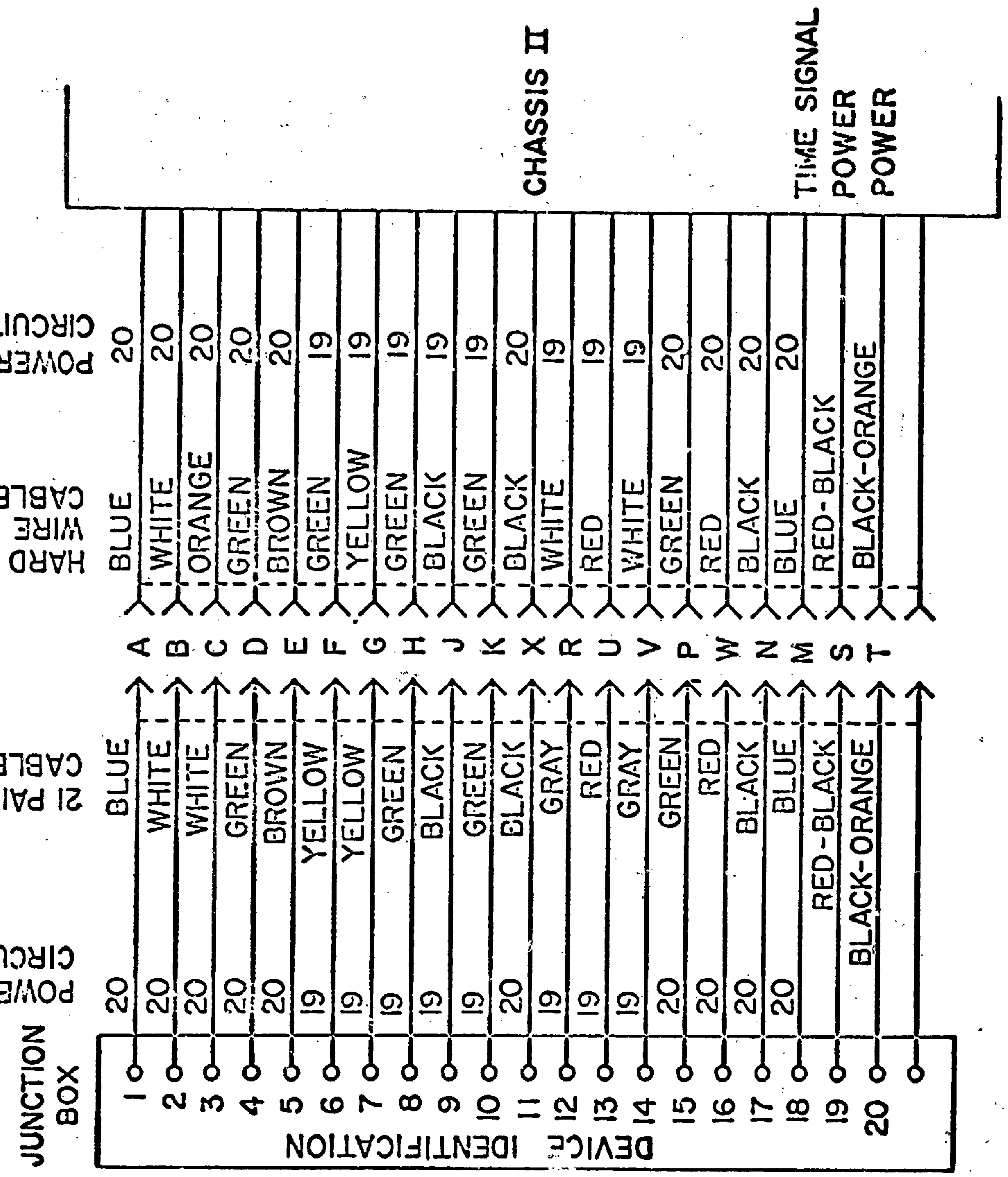

TO CHASSIS I
BLACK
RED
NO.19 PAIR
NO.20 PAIR
ORANGE
BLACK
VOLTAGE CABLE (S)
VOLTAGE CABLE (T)
CHASSIS II
TO CHASSIS I
K X R U V P W N M
10 11 12 13 14 15 16 17 18
15 16 17 18
5 4 3 2 1
9 8 7 6 5 4 3 2 1
J H G F E D C B A
TO CHASSIS I
LETTERS CORRESPOND TO TERMINALS OF CONNECTOR
FILM SWITCH SURROUNDING EACH DEVICE

Figure 5


JUNCTION BOX
DEVICE IDENTIFICATION
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
POWER CIRCUIT
20 20 20 20 20 19 19 19 19 19 20 19 19 19 20 20 20 20
21 PAIR CABLE
BLUE WHITE WHITE GREEN BROWN YELLOW YELLOW GREEN BLACK GREEN BLACK GRAY RED GRAY GREEN RED BLACK BLUE RED-BLACK BLACK-ORANGE
A B C D E F G H J K X R U V P W N M S T
HARD WIRE CABLE
BLUE WHITE ORANGE GREEN BROWN GREEN YELLOW GREEN BLACK GREEN BLACK WHITE RED WHITE GREEN RED BLACK BLUE RED-BLACK BLACK-ORANGE
POWER CIRCUIT
20 20 20 20 20 19 19 19 19 19 20 19 19 19 20 20 20 20
CHASSIS II
TIME SIGNAL
POWER
POWER

EVENTS

Event I

Sometime between July 7, 1966 and July 14, 1966 the following electro-explosive device was initiated by lightning: Explosive Device A (pressure cartridge detonator.) This EED is made of stainless steel and its dimensions in inches are 5/8 hexagonal diameter by 1.125 length. This device had been connected to a 50 foot closed-loop antenna of No. 18 lamp cord. The farthest part of the antenna was cut and stripped with the two ends twisted together and left bare. The firing characteristics* are:

1. Recommended Firing Current: Five amperes applied to the bridge wire results in an average function time of 1.2 milliseconds.

2. Minimum All Fire Current: Minimum recommended all fire current is 3.5 amperes to the bridge wire.

3. No Fire Current: Cartridges stabilized to 240°F were subjected to 1-ampere, 1-watt current applied to the bridge wire for 5 minutes and were then fired at 240°F without evidence of degradation.

4. Insulation Resistance: 100 Megohms minimum resistance when 500 volts DC is applied between the contact pins shorted together and the cartridge body for 1 minute.

5. Static Sensitivity: No ignition when a 0.04 microfarad capacitor charged to 750 volts is discharged from pin to pin and between the contact pins shorted together and the cartridge body. The explosive composition of the device consists of a Hi Shear formulation in the primer and lead azide and RDX or PETN in the base material.

Event II

During an extensive electrical storm, lightning, thunder, hail, heavy rain, and snow on July 14, 1966 between 12:30 and 1:15 PM, the following electroexplosive devices were initiated:

*The firing characteristics of this device were taken from the manufacturer's catalog.

1. An Explosive Device B (explosive bolt) with both bridgewires connected to a 100-foot straight antenna of No. 18 lamp cord with the ends of the antenna cable left open. This device is a dual electrical and mechanical initiating channel isolated to ensure functioning. It is 1.75 inches in diameter and 4.93 inches in length. The bolt contains two (2) explosive charges and is designed to separate at two different points. Each charge contains approximately 10 milligrams of lead styphnate (primer), 220 milligrams lead azide (booster) and 300 milligrams PETN. All explosives will fire on a 580-milliampere, 2-millisecond pulse.

2. An Explosive Device C (detonator) connected to a 100-foot straight antenna of No. 18 lamp cord, with the ends of the antenna cable left open. This EED is 0.75 inch in diameter and 1.0 inch in length with the case made of steel. The detonator is built with a 4.5-ohm single electrical channel with a single bridge wire. The device contains 5.0 milligrams of lead styphnate (primer), 147 milligrams of lead azide (booster), and 237 milligrams RDX (base). The detonator is internally electrostatically shielded and the bridge wire is electrically isolated from the exterior case. All shall fire on a 580-milliampere, 2-millisecond pulse.

3. Two commercial Explosive Devices D (explosive bolts), with dual bridge wires, were also initiated. These devices are 1-1/32 inches in length and 0.189 inch in diameter and are made of non-corrosion resisting steel, cadmium plated. The explosives contained are proprietary. One of these devices was connected to a 200-foot closed loop antenna of No. 22 hookup wire while the other antenna configuration was a 100-foot closed loop antenna of No. 22 hookup wire. Some of the firing characteristics* of these bolts are:

   a. No fire current - 1.0 ampere
   b. 100% fire current - 2.0 amperes
   c. Recommended fire current - 10 or more amperes
   d. Bridge wire resistance - 0.18 $\pm$ 0.03 ohms
   e. Lead wire to bolt body resistance - 2 megohms minimum at 500 volts (DC)
   f. Lead wire to bolt body no fire - 500 volts AC or DC maximum

4. An Explosive Device E (detonator) (with one set of bridge wires hooked up and the other left floating) was connected to an 80-foot straight antenna of No. 18 lamp cord. The device is electrically initiated and capable of symmetrical radial initiation with two electrically isolated bridge wires in a four-pin configuration. The component

*The firing characteristics of this device were taken from the manufacturer's catalog.

is composed of 0.30 gram lead styphnate (primer), a lead aside (0.1 gram) booster and (1.060 grams) of RDX as a base charge. The dimensions in inches are 0.614 diameter and 1.00 length. The device has a bridge resistance of 4-5 ohms. Its functional current is 1.0 ampere for no fire, and 0.580 for all fire.

5. A commercial Explosive Device F (initiator), with its bridgewire connected to a 100-foot closed loop antenna of No. 22 hookup wire, was also set off by this lightning stroke. Since the manufacturer of this device is no longer in business, the firing characteristics* and the explosive composition have been difficult to obtain. Investigation is being continued.

Event III

The first recorded initiation of the electroexplosive devices by lightning occurred on July 29, 1966. The zero reading of the 30 kV scale was displaced as much as 3 to 4 kV. Exact calibration was, therefore, uncertain so all of the values given in this report are relative to an arbitrary zero. The detonation occurred at 17:32:33 (hours:minutes:seconds). The amplitude of the offset of the trace line was 2.7 divisions with respect to the grid lines. This is about 0.27 inch or 6.86 millimeters.

The electric field was originally positive at the beginning of the electrical activity, but the field was driven to the negative by three major strokes. The first, approximately 17:20, drove the field to +10.2 kV. Then at 17:21 the stroke drove the field to +3.6 kV. Five minor strokes occurred in the next 10 minutes. None of these strokes drove the field negative. Then the detonating stroke occurred at exactly 17:32:23. The field before the stroke was approximately -9 kV. The maximum field at the time of the stroke was +7.2 kV. The field after the stroke was approximately -10.8 kV.

Three to five minutes after the detonating stroke, the field dropped to approximately -3kV and remained there for about 30 minutes. The precipitation center of this storm was located at an azimuth of 225 degrees and a distance of about 3 to 4 miles from the laboratory at the time of the detonation. Only one device was initiated at this time. This was Explosive Device D (a commercial explosive bolt). Its dual bridge wire was connected to a 100-foot closed loop antenna of No. 22 hookup wire.

*The description, explosive composition, and firing characteristics of this device have been stated previously under Event II.

Event IV

At 12 Noon on the 4th of August, 1966, a sheet of rain was noticed moving very rapidly toward the laboratory. It came from the east and was first noticed about 2500 feet south of timber peak. The precipitation appeared to die out within about 2 minutes after the first sighting. By 12:05 PM a thunderstorm was visible to the east and it approached the laboratory at a fairly rapid pace. Also, at the same time, the electric field increased rapidly and quickly reached a value of -7.0 kV.

The storm at the laboratory lasted a little over an hour and as many as 50 strokes of lightning were recorded during the storm. These strokes ranged between 5 miles and 500 feet of the laboratory. It rained very heavily during a few periods of the storm and also hail fell during the latter part of the storm in sufficient amounts to leave white areas.

The first stroke, recorded at 12:27:57, appeared to hit directly east of the laboratory and the second appeared to hit to the south. The electric field just before the stroke rose to -6.9 kV, and at the same time of the stroke, the field was driven to +0.9 kV. The first stroke initiated the following electroexplosive devices:

1. The dual bridge wires of Explosive Device G <u>pressure cartridge</u> were secured to an 80 foot straight antenna of No. 18 lamp cord with the ends of the cable left open. This stainless steel EED is a gas and heat generating, initiating and pressure-producing cartridge. Its dimensions are 5/8 inch in diameter by 1.110 $\pm$ 0.015 inches in length.

   Some of its firing characteristics* are:

   a. <u>Recommended Firing Current</u> - Five amperes applied to one bridge wire or to each bridge wire results in an average function time of 1.2 milliseconds.

   b. <u>Minimum Recommended All Fire Current</u> is 3.5 amperes to one bridge wire or to each bridge wire.

   c. <u>No Fire Current</u>: Cartridges stabilized to +350°F were subjected to 2-ampere, 1-watt current applied for 5 minutes to both bridge wires simultaneously and were then fired at ambient temperatures without evidence of degradation.

*The firing characteristics of this device were taken from the manufacturer's catalog.

d. Insulation Resistance: 100 Megohms minimum insulation resistance when 500 volts (DC) is applied between the contact pins shorted together and the cartridge body for 1 minute.

e. Static Sensitivity: No ignition occurs when a 500 micro-microfarad capacitor, charged with 5000 volts is discharged between the contact pins shorted together and the cartridge body.

f. Radio Frequency Hazards: Test samples were exposed to a range of 8 to 10,000 megacycles with a power input of 0.10 watt to each bridge wire. All cartridges tested passed without firing or degradation as evidenced by subsequent firing tests. The explosive composition is proprietary and less than 1.0 gram.

2. Two Explosive Devices H (initiators) were set off by the same stroke of lightning. A 100 and a 200-foot closed loop antenna of No. 22 "hookup" wire were connected to the bridge wire of each device. This EED is a heat and pressure-producing initiator. The average pressure produced is approximately 30,000 psi in a 1-cc closed volume. The pressure rise to maximum value occurs in approximately 1 millisecond. The initiator contains a .005 inch diameter welded (alloy 800) bridge wire with a nominal 0.18 $\pm$ .02 ohm resistance. The initial charge is 125 milligrams of $AL/KClO_4$ with a booster charge of 125 milligrams of pistol powder. The nominal output of the initiator is 85 ft-lbs of kinetic energy at 30,000 psi pressure. The nominal characteristics are:

a. No fire current: 5 amp/5-watt
b. Minimum fire current: 7 amps for 10 seconds
c. Minimum 100% fire current: 15 amps for 50 milliseconds
d. Recommended fire current: 22 amps for 20 milliseconds
e. Maximum test current: 1 amp (continuous)

The static charge sensitivity is above 600 picofarads capacitance at 25,000 volts with zero series loop resistance. The impact sensitivity of the $AL/KClO_4$ is greater than 100 cm with a 2-kilogram weight. The impact sensitivity of the powder is 55 cm with a 2-kilogram weight. The heat sensitivity for auto-ignition of the $AL/KClO_4$ is greater than 585 and 242°C for this powder.

3. An Explosive Device E (detonator) (with one bridge wire hooked up and the other bridge wire left floating) connected to an 80-foot straight antenna of No. 18 lamp cord with the ends of the antenna cable left open, was initiated. The description, explosive composition, and firing characteristics of this device have been stated previously under Event II.

4. A commercial Explosive Device D (<u>explosive bolt</u>) was also initiated. This device is 1-1/32 inches in length and 0.189 inch in diameter and is made of noncorrosion resisting steel, cadmium plated. The explosives contained are proprietary. The dual bridge wires of this device were secured to a 100-foot closed loop antenna of No. 22 hookup wire. Some of the firing characteristics* of this bolt are:

   a. No fire current - 1.0 ampere
   b. 100% Fire current - 2.0 amperes
   c. Recommended fire current - 10 or more amperes
   d. Bridge wire resistance - 0.18 ± 0.03 ohm
   e. Lead wire to bolt body resistance - 2 megohms minimum at 500 volts (DC)
   f. Lead wire to bolt body no fire - 500 volts AC or DC maximum

5. A commercial high-pressure Explosive Device F (<u>initiator</u>), with its bridge wire connected to a 100-foot closed loop antenna of No. 22 hookup wire, was also set off by this lightning stroke. Since the manufacturer of this device is no longer in business, the firing characteristics and the explosive composition have been difficult to obtain. Investigation is being continued.

6. Explosive Device A, a commercial <u>detonator</u> cartridge, was connected to a 200-foot closed loop antenna of #59B radio frequency cable by means of a single bridge wire. The dimensions in inches of this stainless steel device are 5/8 hexagonal diameter by 1.125 length. The description, explosive composition and the firing characteristics of this device have been stated previously under Event I.

<u>Event V</u>

On the same day, August 4, 1966 at exactly 12:35:26, two additional electroexplosive devices were initiated. The electrical field before this stroke was -4.0 kV. The stroke drove the field to +3.4 kV. The two devices were:

1. An Explosive Device C(<u>detonator</u>) with its single bridge wire connected to a 100-foot straight antenna of No. 18 lamp cord with the ends of the antenna cable left open. The description, explosive composition and the firing characteristics of this device have been stated previously under Event I.

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*The firing characteristics of this device were taken from the manufacturer's catalog.

2. A commercial Explosive Device I (pressure cartridge), having a single bridge wire connected to a 50-foot straight antenna of No. 18 lamp cord with the ends of the antenna cable left open, was also set off by this stroke.

Some of its firing characteristics* are:

a. 0.25 Ampere maximum positive no fire for 30 seconds at ambients not exceeding 95°F.
b. 1 Ampere positive fire
c. 0.001 Second operation ignition to maximum pressure buildup at 2 amperes maximum firing
d. Operating range -60 to +160°F
e. 1000-Volt AC breakdown
f. Capable of withstanding applicable shock and vibration
g. Bridge resistance: 0.6 to 1.2 ohms.
h. Explosive composition: Primer - Diazo (DDNP) 60 mg. ± 3 mg.

Event VI

On August 8, 1966, the storm began affecting the field at about 13:08, when the field meter went off scale at an amplifier setting of 2 kV. The amplifier setting was changed to 10 kV at 13:11. The storm was first noticed visually at 13:40. The center of precipitation and electrical activity of the storm seemed to coincide and was positioned at 315 degress (azimuth) and about 5 miles from the laboratory at this time. The negative field created by the storm reached its highest point at -8.6 kV at 13:58.

The detonating stroke occurred at 14:20:42. The field before the stroke was -8.0 kV and the stroke drove the field to +4.4 kV. This stroke occurred within 2000 feet south of the laboratory. This stroke knocked out the time code generator and the regulated power supply.

The storm had passed sufficiently to the east by 14:37 to make the field positive.

Eight electroexplosive devices were initiated by this lightning bolt:

1. A charge assembly from an Explosive Device J (explosive bolt) with its single bridge wire connected to a 50-foot straight antenna of No. 18 lamp cord with the ends of the antenna cable left open. This device is approximately 1.0 inch in diameter and 2.0 inches in

*The firing characteristics of this device were taken from the manufacturer's catalog.

length. The explosive composition consists of 0.020 milligram of lead styphnate and lead azide (50/50) in the primer. A 0.075 milligram (50/50 mixture) of lead azide and PETN is contained in the booster, while the base charge consists of 0.180 milligram of RDX. The functional current for "no fire" is 0.100 ampere and for "all fire" is 0.750 ampere. The bridge resistance is 4-5 ohms.

2. A No. 6 blasting cap connected to a 200-foot closed loop antenna of No. 22 hookup wire. This unit is 3/8 inch diameter by 2 inches long and is of low static sensitivity with a bridge resistance of 1.5 to 2 ohms. Its explosive composition consists of 1.0 gram of lead styphnate in the primer, 1.0 gram of lead azide in the booster, and approximately 5.0 grams of RDX as the base charge.

The description, explosive composition and firing characteristics of the following five electroexplosive devices which were also detonated by this same stroke, have been previously documented in this report. The antenna configuration and the hookup associated with each EED was as follows:

a. A commercial Explosive Device D (explosive bolt) was also initiated. The dual bridge wires of this device were secured to a 100-foot closed loop antenna of No. 22 hookup wire.

b. Two Explosive Devices E (<u>detonators</u>) were set off at the same time. One of these devices, with one set of bridge wires hooked up and the other left floating, was connected to a 50-foot closed loop antenna of No. 18 lamp cord.

   The other Explosive Device E (<u>detonator</u>), with its dual bridge wires, was secured to a 100-foot straight antenna of No. 18 lamp cord. The ends of the antenna cable were left open.

c. An Explosive Device C (<u>detonator</u>) with its single bridge wire was connected to a 50-foot straight antenna of No. 18 lamp cord. The ends of the antenna cable were left open.

d. The dual bridge wires of an Explosive Device G (<u>pressure cartridge</u>) were secured to a 100-foot closed loop antenna of No. 59B radio frequency cable. The antenna loop was placed inside of a 200-foot closed loop antenna of the same description.

3. An Explosive Device L (<u>detonator</u>), having a single bridge wire and connected to an 80-foot straight antenna of No. 18 lamp cord, was also initiated. The ends of the antenna cable were spliced and the wires frayed in a finger-type configuration.

This detonator is a high-energy bridge wire EED used for various test purposes. It is a precision electric device which, on being furnished a suitable electric impulse, will initiate and furnish explosive energy with consistent performance. Its size is 1.19 inches in length and 0.67 inch in diameter.

Its function is: The EBW initiates the PETN (0.250 gram) in the primer which in turn initiates a pellet of tetryl or 9407 PBX (0.050 gram) in the booster section.

Its firing characteristics are:

a. No fire current:	0.1 ampere
b. 100% Fire current:	375-500 amperes with 1500 volts and 1 microfarad at 70°F.
c. Recommended fire current:	250 amperes
d. Bridge wire resistance:	0.1 ohm

Event VII

On August 9, 1966, the storm affected the field meter at about 13:17 when the record went off scale at a setting of 2 kV. The amplifier was then set on 10 kV at 13:40.

The storm was first noticed visually at 13:45. The center of precipitation and electrical activity appeared to coincide and was located at an azimuth of 330 degress at about 4 miles.

At 14:08, there was rain at the laboratory and the center of electrical activity was directly north about 3 miles in line with the explosive container.

The detonating stroke occurred at 14:22:40 and the lightning flash appeared to be west of the laboratory and within one mile. No change in the field was being recorded at this time due to a malfunction in the field meter.

At 15:00, some hail was falling and the storm was moving east with a fog bank moving in rapidly from the north.

Only one device was detonated at this time: An Explosive Device M (squib), having a single bridge wire, was connected to a 200-foot closed loop antenna of No. 18 lamp cord. This EED contains 0.2 gram of a commercial ignition powder and 1.0 gram of A5 black powder, unpressed. The minimum firing current averages .02 ampere ± 10% with a firing time of 78.8 milliseconds. The approximate size of this device in inches is 0.25 diameter by 0.875 length.

Event VIII

On August 26, 1966, an electrical storm, accompanied with rain showers and a large quantity of hail, was noticed at the laboratory at 13:30. An Explosive Device N (pressure cartridge) was initiated by a stroke of lightning at exactly 14:10:34. This device was connected to an 80-foot, straight antenna of No. 18 lamp cord. The electrical field meter data was lacking from the daily log for this storm. Information will be obtained from New Mexico Tech at a later date.

The firing characteristics of this dual bridge wire EED, as taken from the manufacturer's catalog, are:

1. No fire current:	0.5 ampere
2. 100% fire current:	1.0 ampere
3. Bridge wire resistance:	1.0 ± 0.15 ohms
4. Pin to case resistance:	2 megohms minimum at 500 volts DC
5. Pin to case no fire:	1000 volts DC or 1000 volts AC
Explosive Load:	
Prime:	Manufacturer's formulation
Main Charge:	Manufacturer's formulation
Energy Output:	135 foot pounds

ACKNOWLEDGMENT

Without the valuable assistance of the following individuals, this report would not have been made possible:

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Dr. George Griswold
Mr. and Mrs. Earl Montgomery
Mr. Richard Chamberlin
Mr. Richard Carlson

Personnel from Sandia Corporation:

V. W. Christy
J. P. Sutton, Jr., (Summer Hire).

ELECTRICAL SCHEMATICS

and

ANTENNAE CONFIGURATIONS

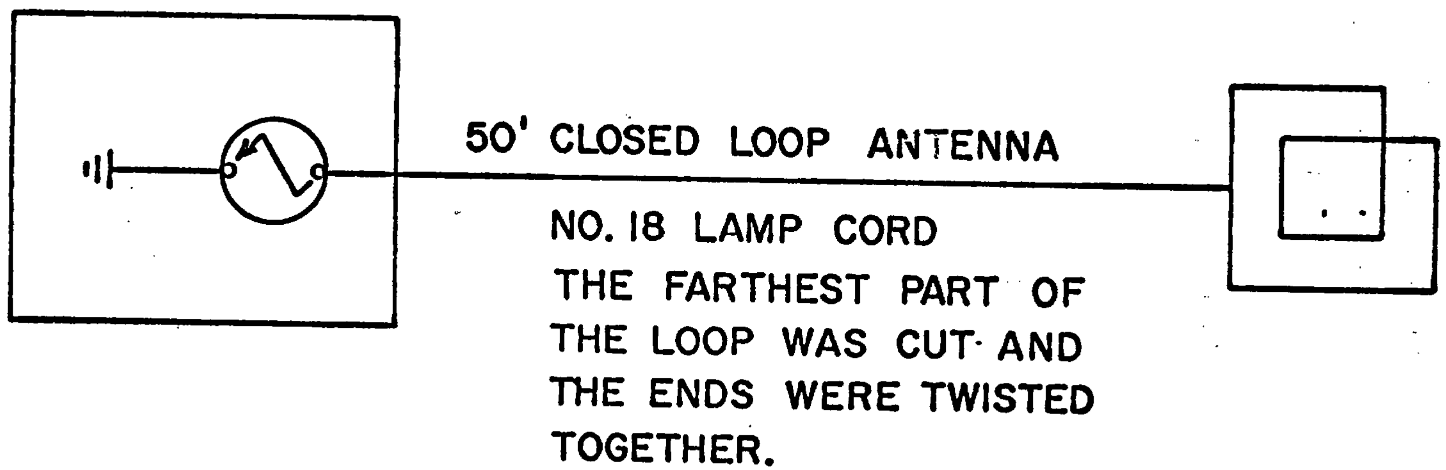
of the

INITIATED DEVICES

1.

EXPLOSIVE DEVICE A.

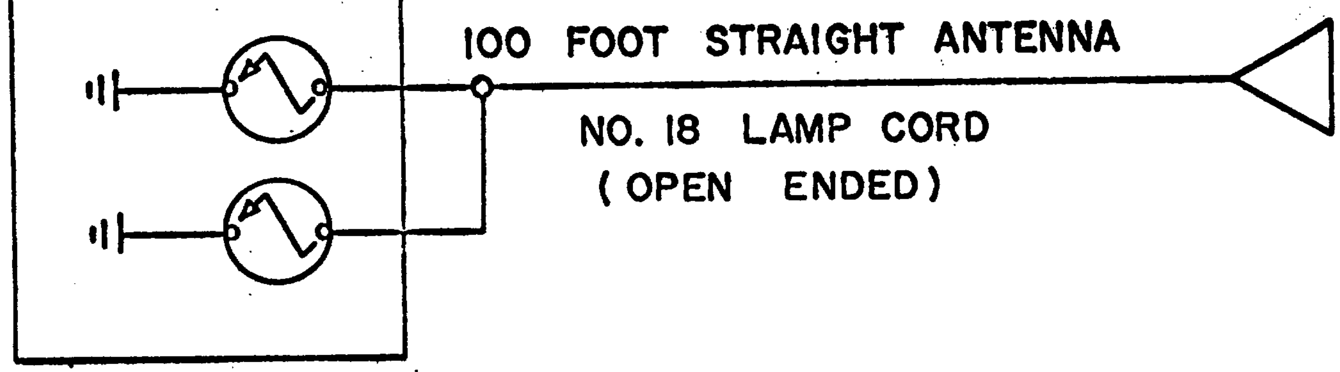
PRESSURE CARTRIDGE DETONATOR



2.

EXPLOSIVE DEVICE B

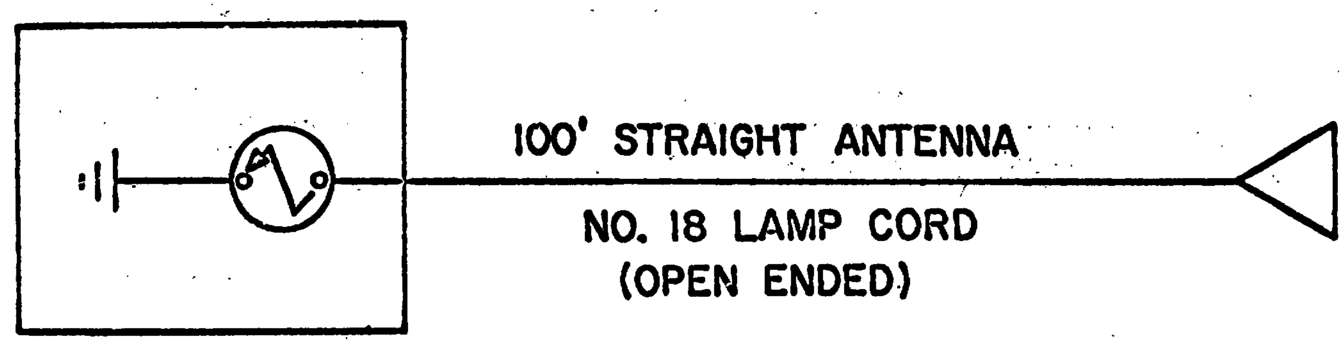
EXPLOSIVE BOLT



3.

EXPLOSIVE DEVICE C

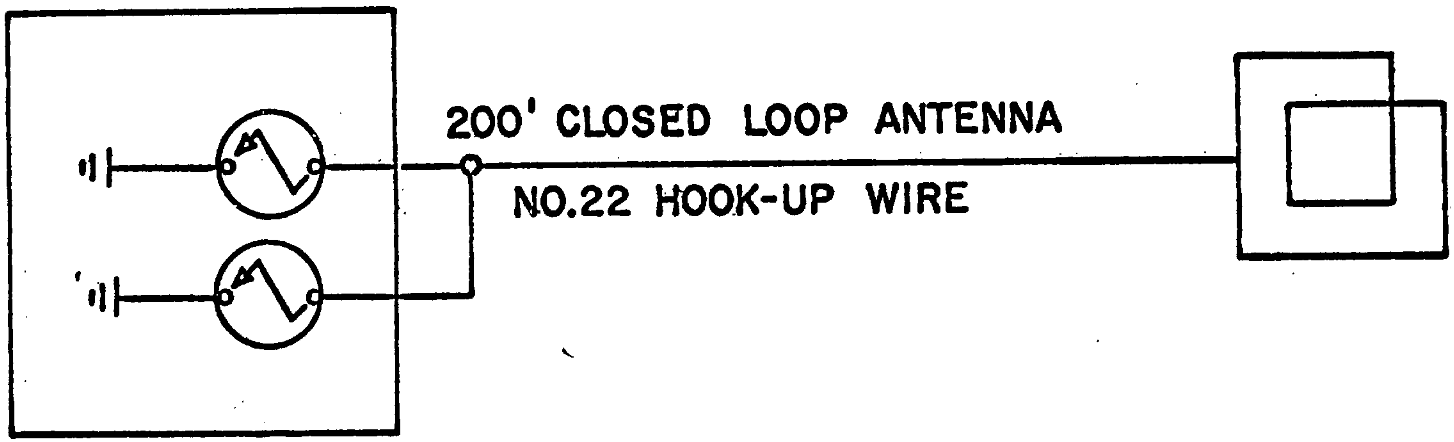
DETONATOR



4.

EXPLOSIVE DEVICE D

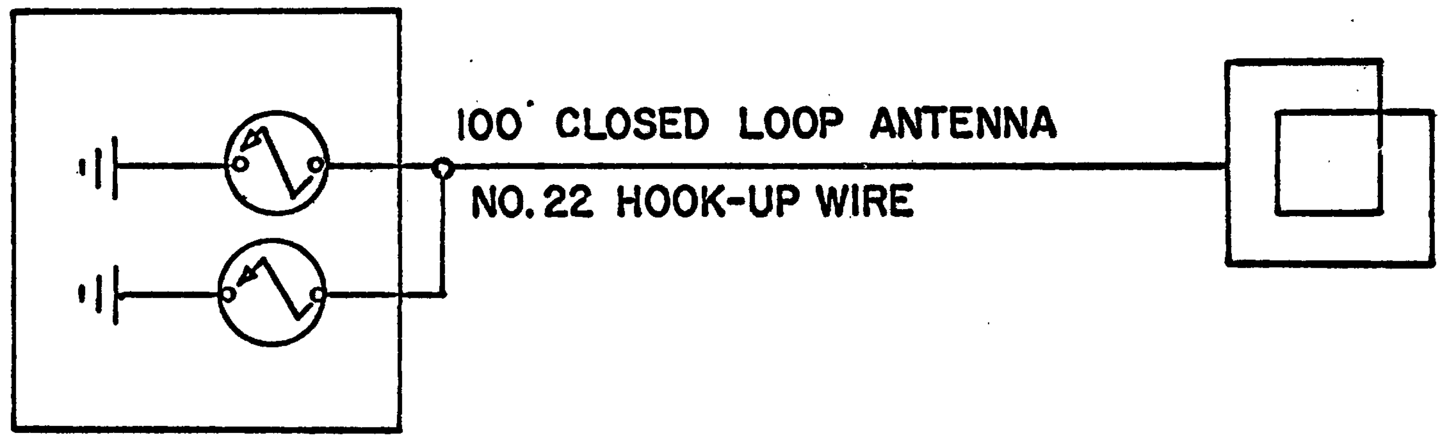
EXPLOSIVE BOLT



5.

EXPLOSIVE DEVICE D

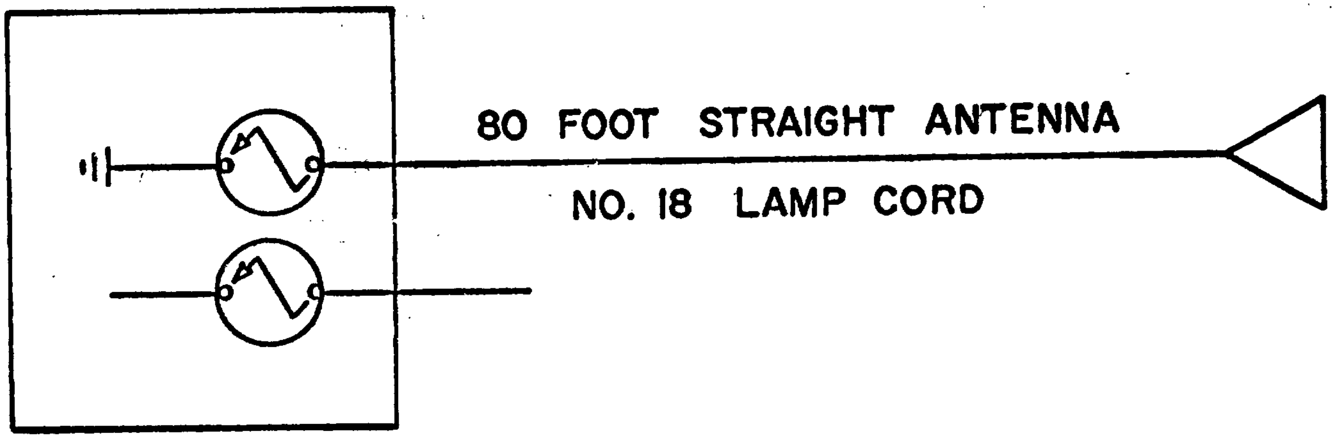
EXPLOSIVE BOLT



6.

EXPLOSIVE DEVICE E

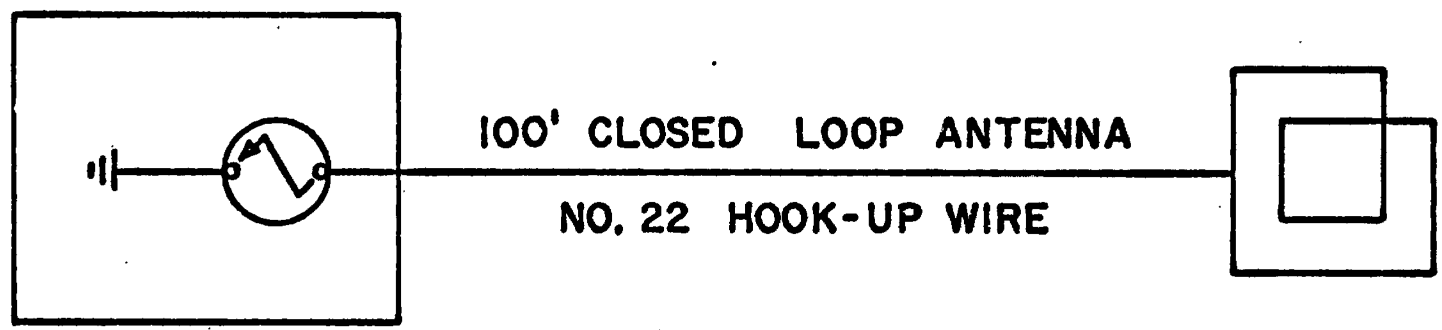
DETONATOR



7.

EXPLOSIVE DEVICE F

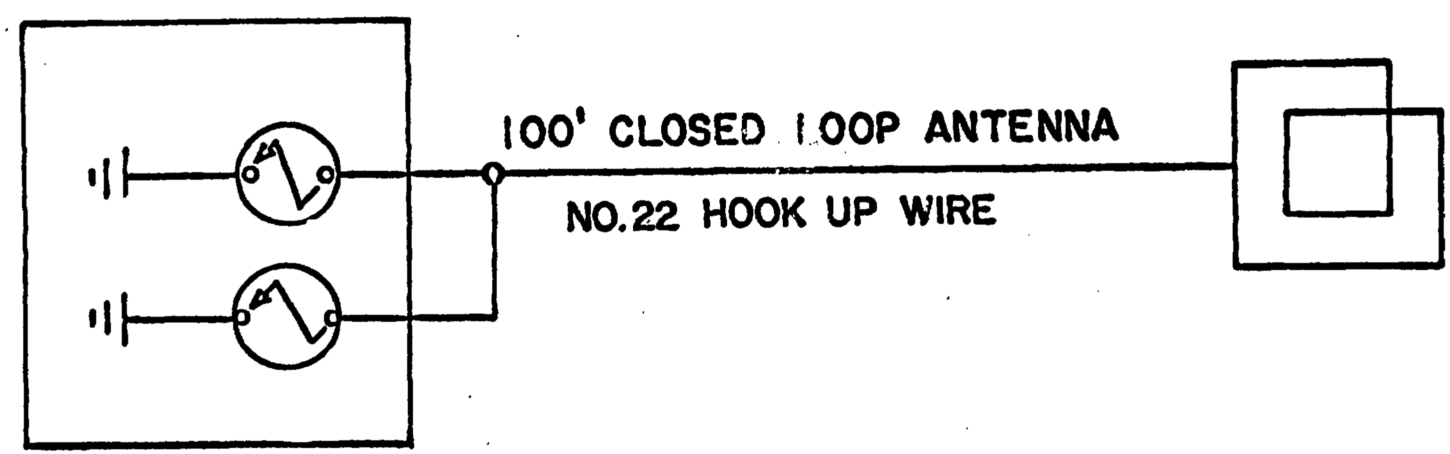
HIGH PRESSURE
INITIATOR



8.

EXPLOSIVE DEVICE D

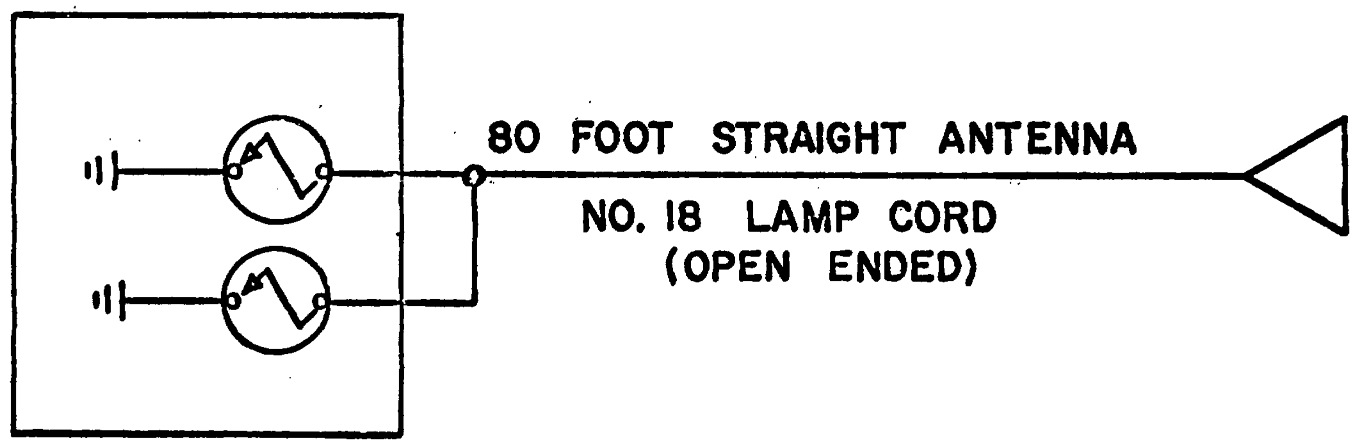
EXPLOSIVE BOLT



9.

EXPLOSIVE DEVICE G

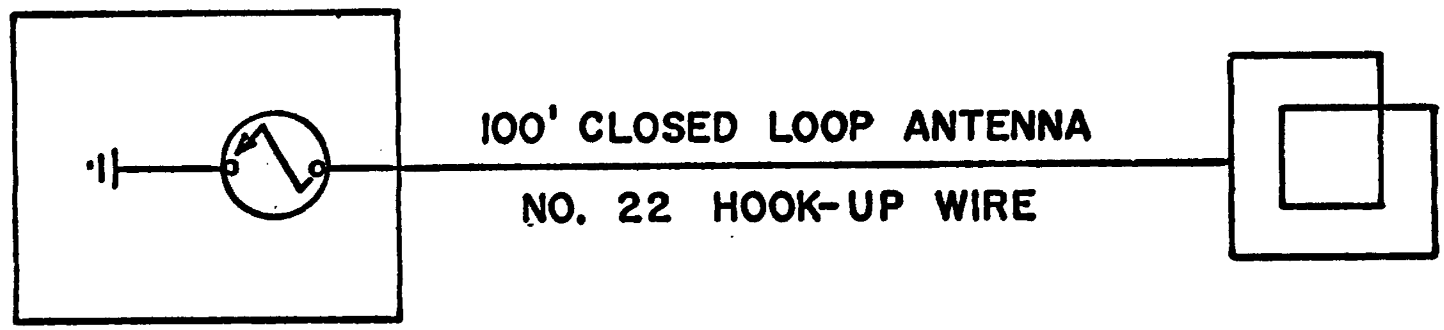
PRESSURE CARTRIDGE



10.

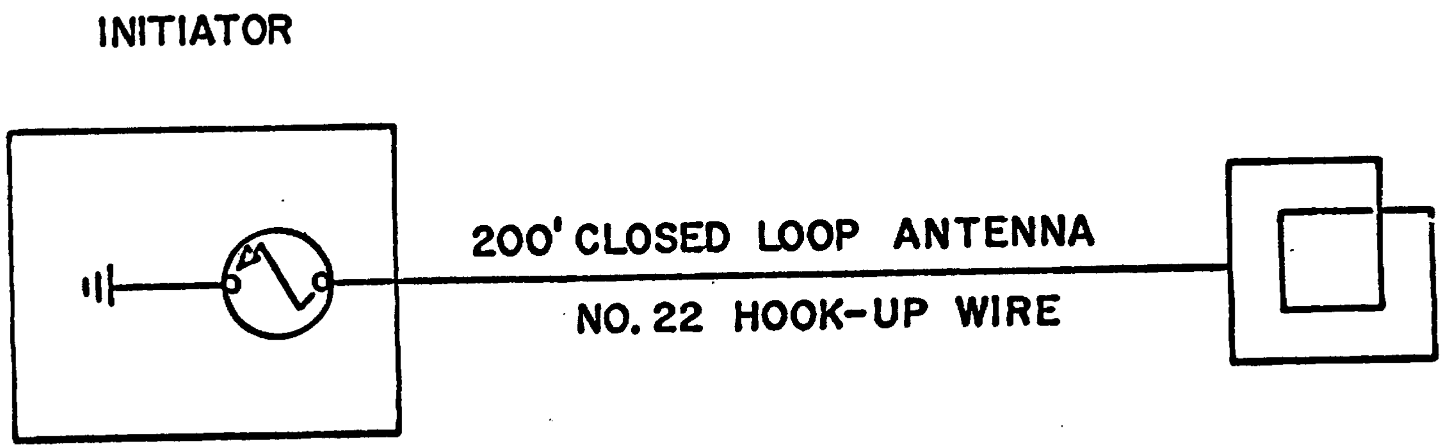
EXPLOSIVE DEVICE H

INITIATOR



11.

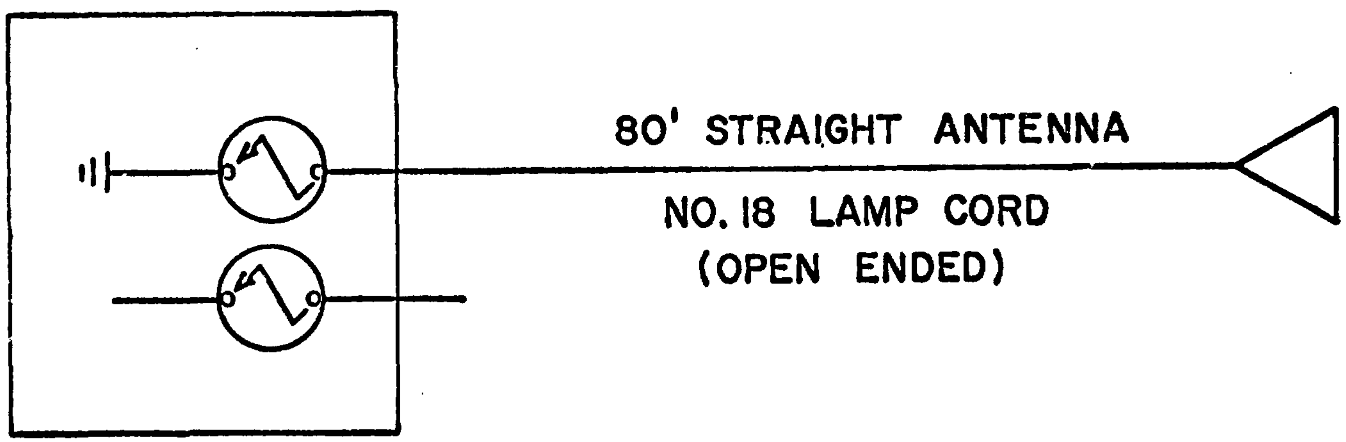
EXPLOSIVE DEVICE H



12.

EXPLOSIVE DEVICE E

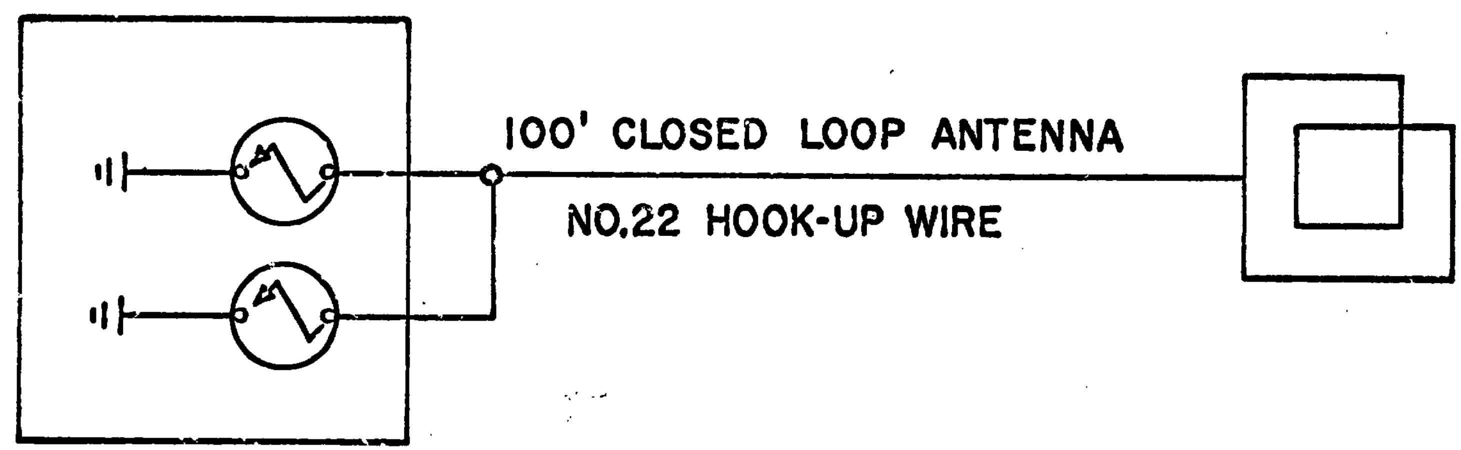
DETONATOR



13.

EXPLOSIVE DEVICE D

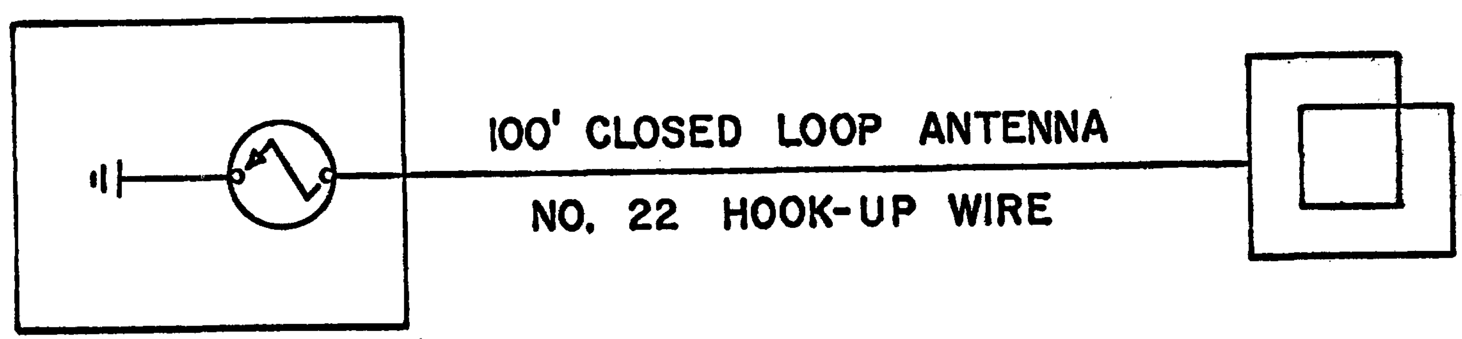
EXPLOSIVE BOLT



14.

EXPLOSIVE DEVICE F

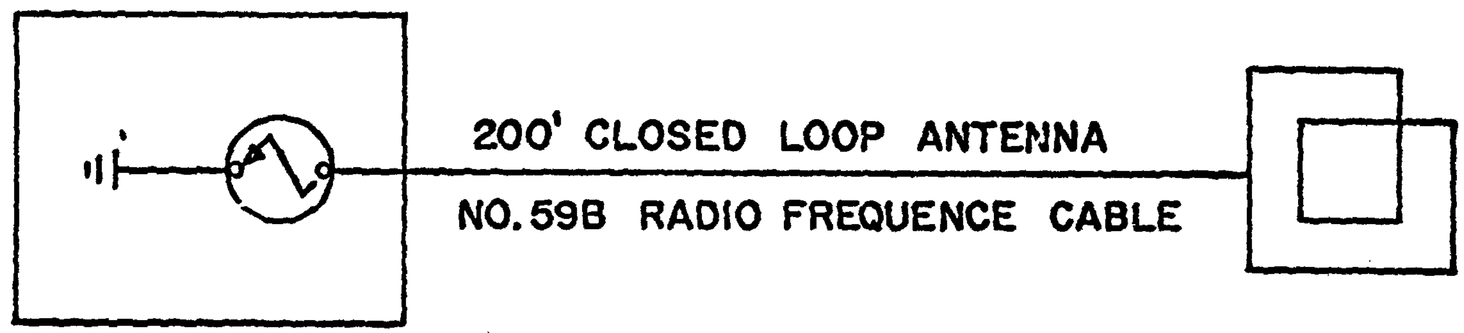
INITIATOR



15.

EXPLOSIVE DEVICE A

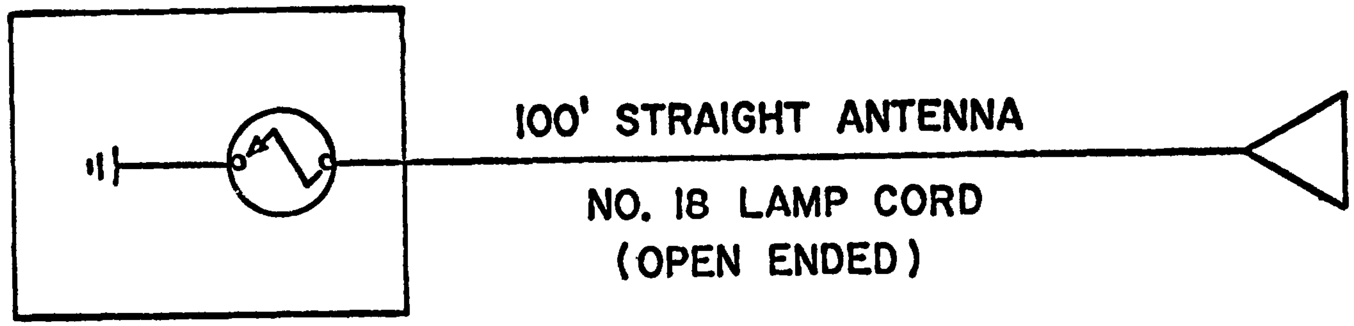
PRESSURE CARTRIDGE
DETONATOR



16.

EXPLOSIVE DEVICE C

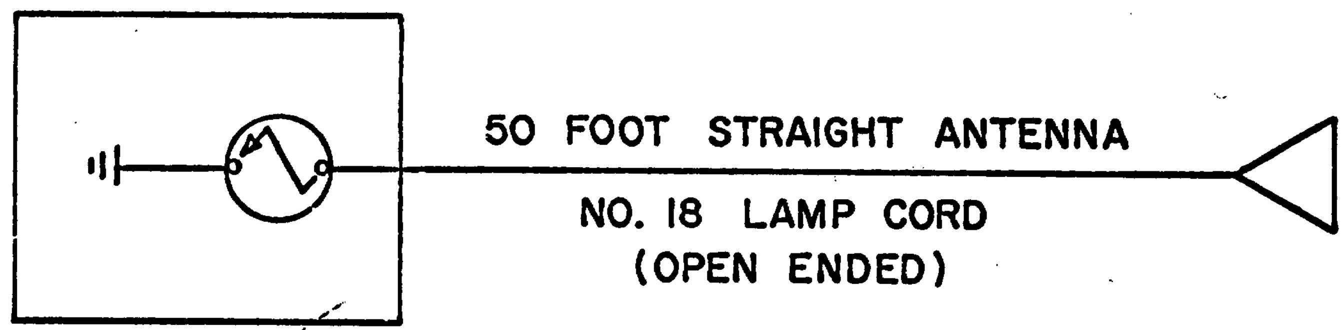
DETONATOR



17.

EXPLOSIVE DEVICE I

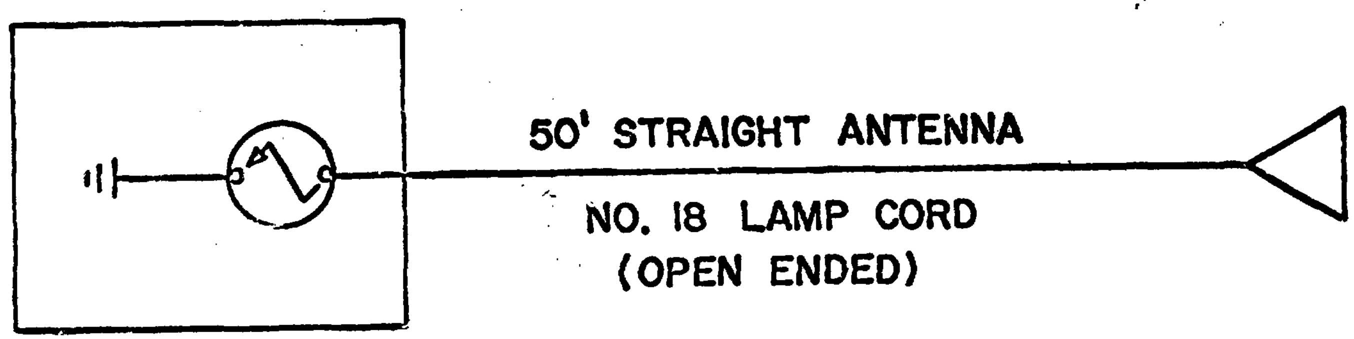
PRESSURE CARTRIDGE



18.

EXPLOSIVE DEVICE J

EXPLOSIVE BOLT



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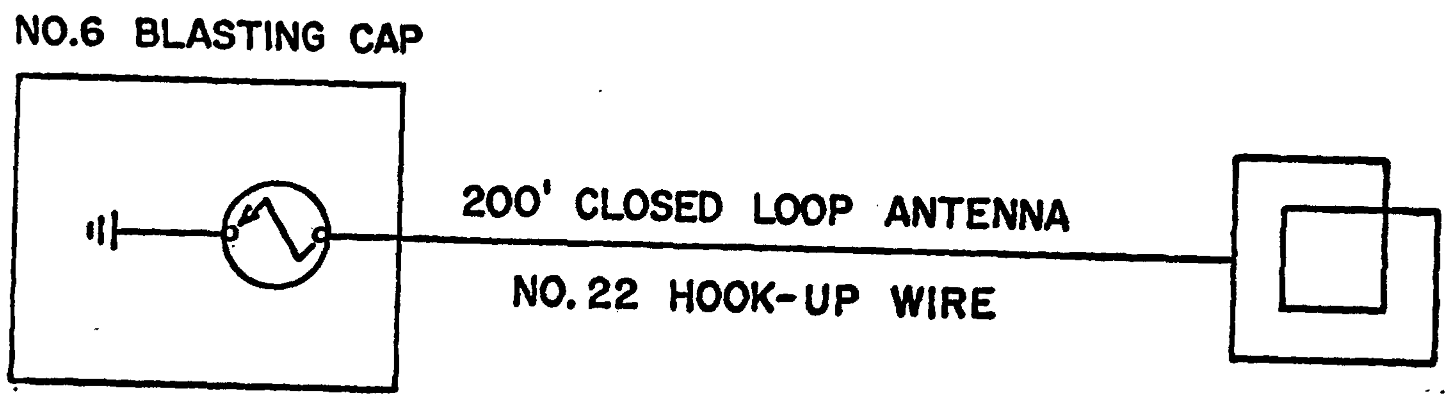
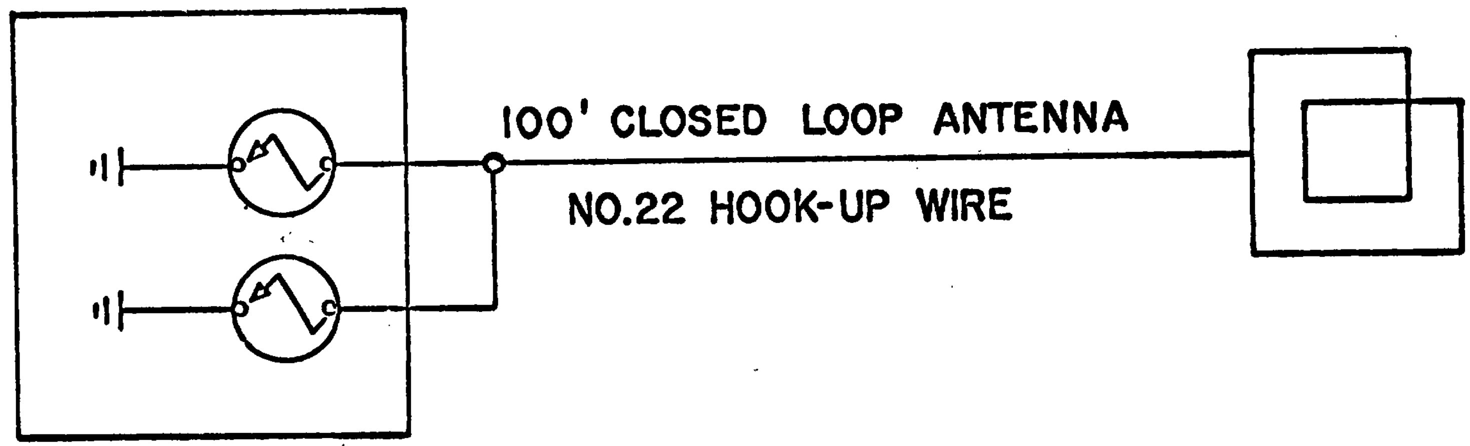


20.

EXPLOSIVE DEVICE D

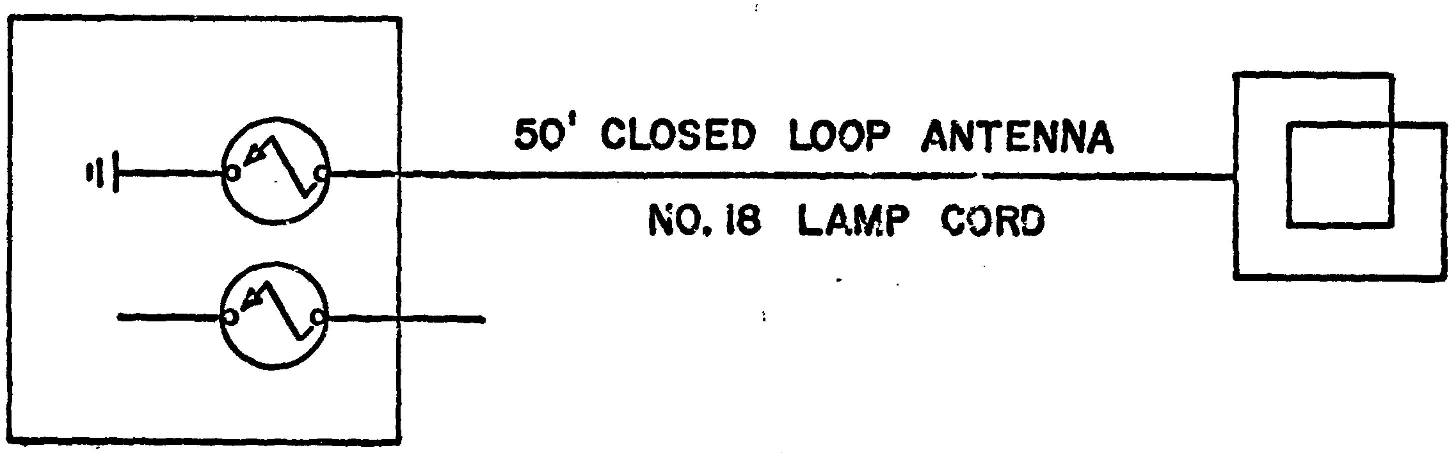
EXPLOSIVE BOLT



21.

EXPLOSIVE DEVICE E

DETONATOR



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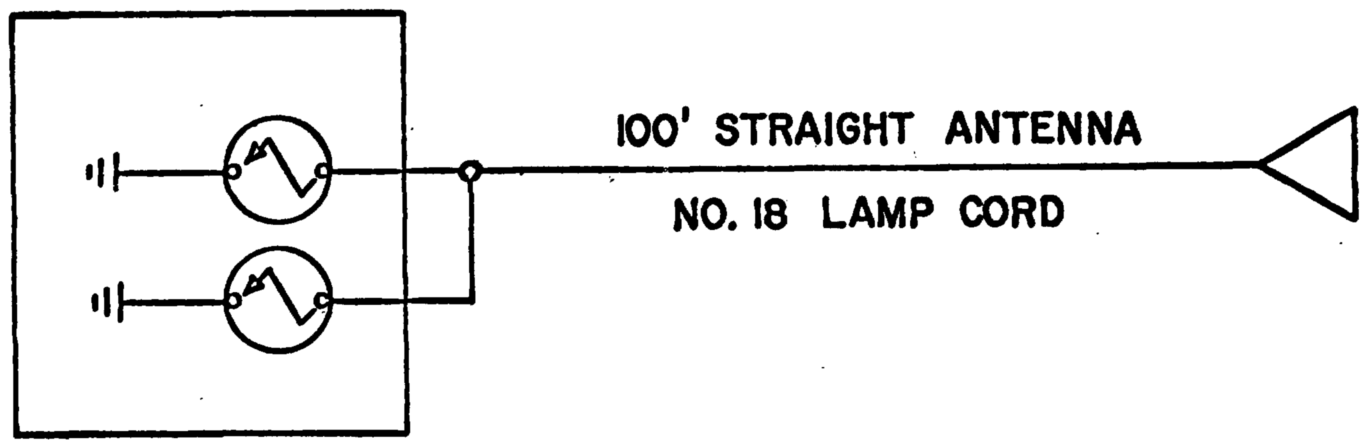
EXPLOSIVE DEVICE E

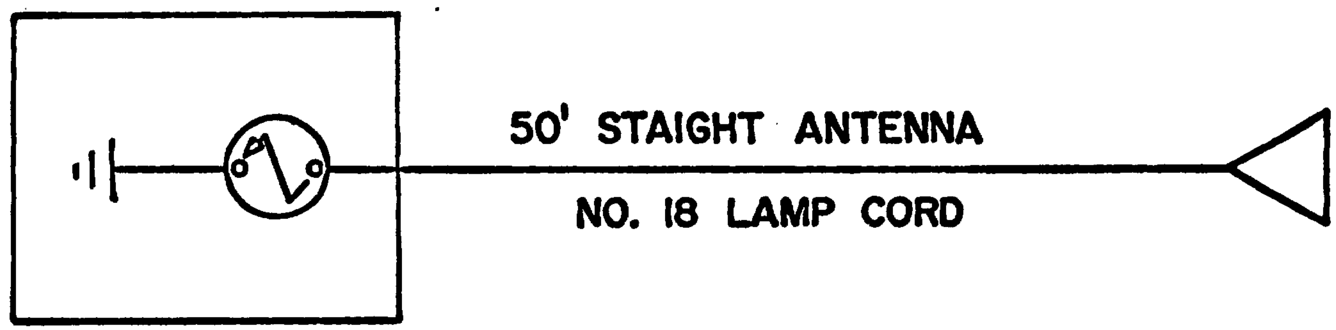
DETONATOR



23.

EXPLOSIVE DEVICE C

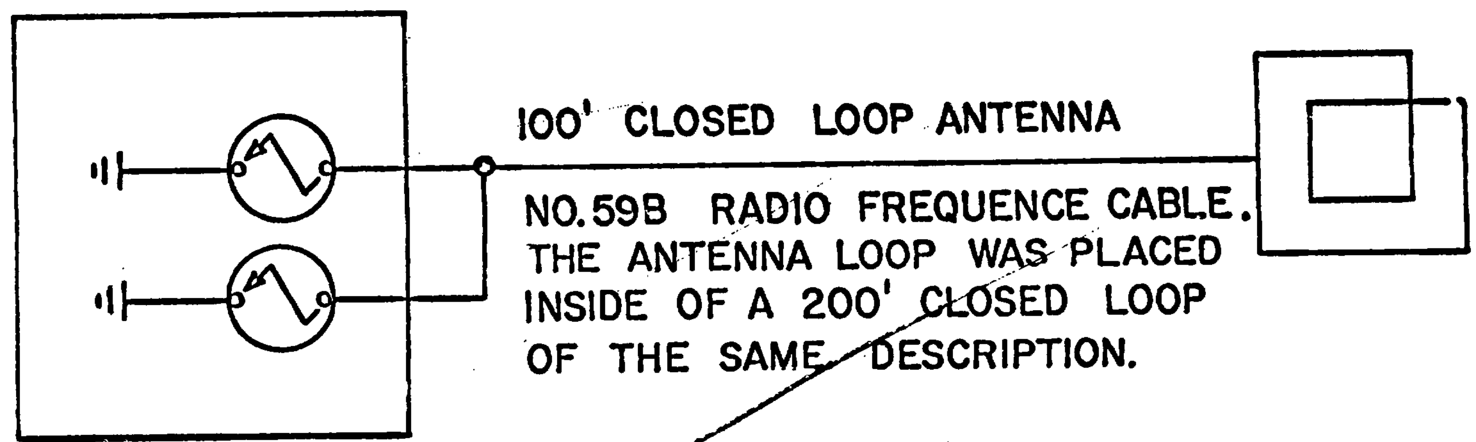
DETONATOR



24.

EXPLOSIVE DEVICE G

PRESSURE CARTRIDGE



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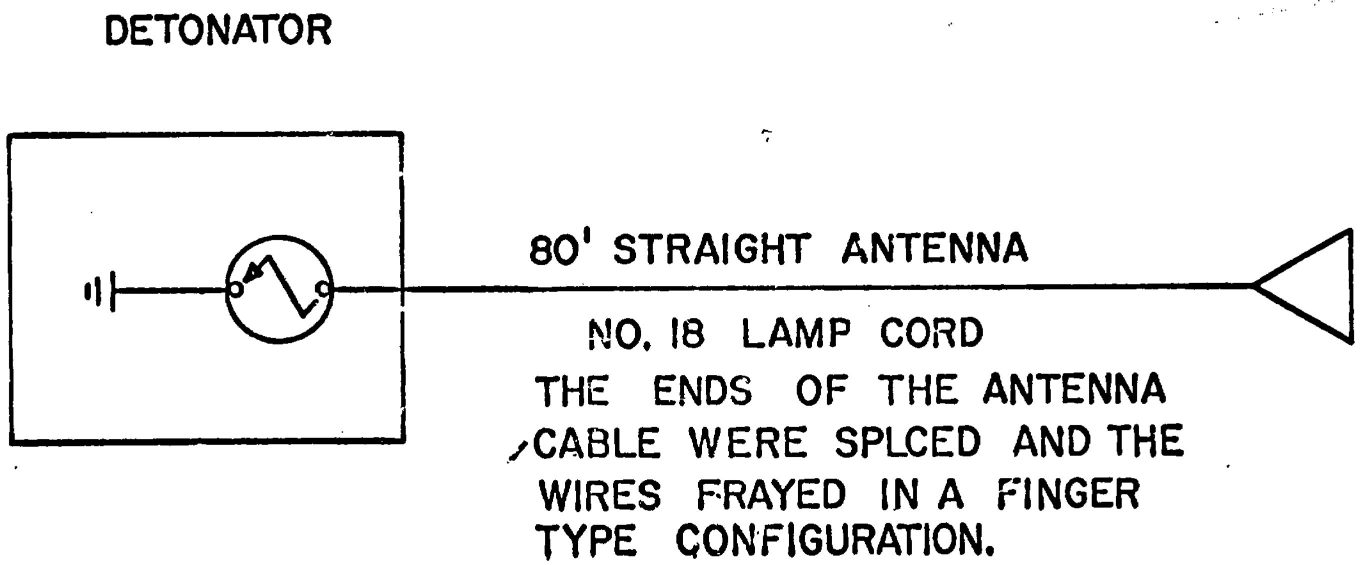
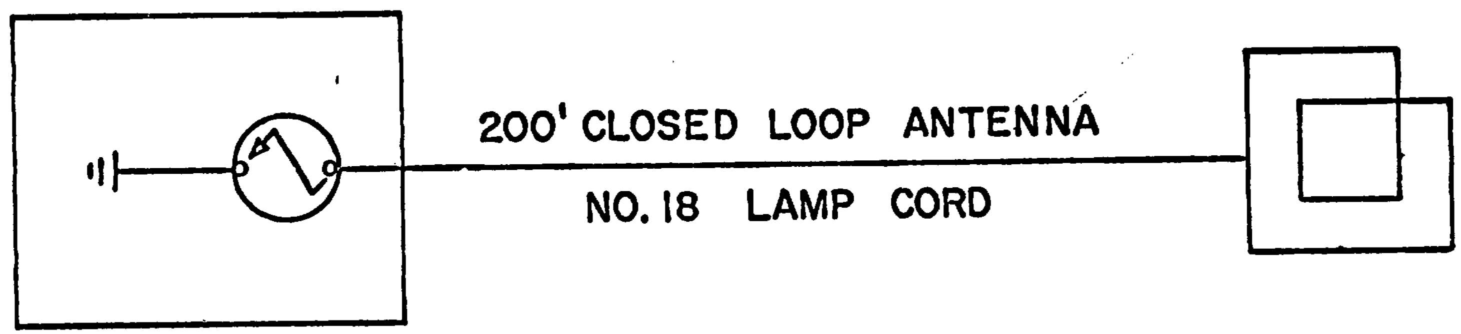
EXPLOSIVE DEVICE L



26.

EXPLOSIVE DEVICE M

SQUIB



27.

EXPLOSIVE DEVICE N

PRESSURE CARTRIDGE

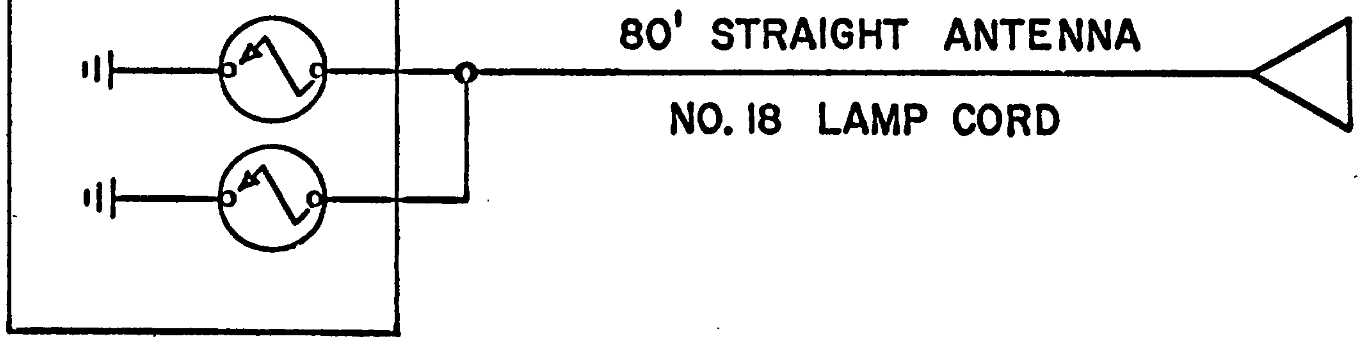


TABLE 1

DATA PRESENTATION

(at approximately 20 mil thickness)

	Powder	Resistivity (Ω-cm)	Dielectric strength (volts/mil)	Density (gm/cm^3)
Primary Explosive	Normal Unmilled Lead Styphnate	10^{13}	140	2.5
	Basic Lead Styphnate	10^{14}	100	2.5
	Lead Styphnate with 2% Viton A	3×10^{12}	120	2.5
	Lead Azide	5×10^{10}	90	3.7
	75% Lead Azide 25% Lead Styphnate	9×10^{12}	130	2.5
Secondary Explosive	PETN	3×10^{12}	130	1.7
	RDX	5×10^{13}	110	1.5
	HMX	4×10^{10}	90	1.4
	HNS	5×10^{13}	400	1.5
Pyrotechnics & misc. mixes	Bullseye	4×10^{4}	< 5	- -
	Black Powder	10^{6}	< 5	1.6
	$BKNO_3$ Powder	3×10^{12}	70	.95
	80% PETN 20% Graphite	500	<5	1.5
	PbO_2 - Al mix	3×10^{10}	<9	4.3
	$KClO_4$ - Al mix	3×10^{3}	<5	2.1
	$KClO_4$ - Zr mix	4×10^{10}	<5	2.5

APPENDIX A

TABLE 1

	Dielectric Strength V/mil	Dielectric Constant	Resistivity Ohm-cm	Source
HEADER MATERIAL				
Alumina 1510 (porous)	50 (1/4" thick)	5.5	10^{14}	Carborundum
Alumina 1542 96% (dense)	200 (1/4" thick)	9.2	10^{14}	Carborundum
Steatite 302	250 (1/4" thick)	5.58	-	Centralab
Boron Nitride	500	-	-	Union Carbide Corp.
Beryllia 7198	258	6.93	2×10^{14}	Frenchtown Porcelain
Glass Boro-silicate	1000	4.7	$> 10^{14}$	Corning Glass
INSULATION				
Mylar	4000	3.1	10^{19}	DuPont
Kapton	7000 (1 mil thick)	3.5	10^{18}	DuPont
Lexan	3910 (1.5 mils thick)	3.17	2.1×10^{16}	General Electric
Teflon	2500	2.0	—	Technical Fluorocarbon
Tedlar PVF film	3500	8.5		Technical Fluorocarbon
Scotchtite 3028	1400 (.010" thick)	5.3	30×10^{14}	3M Company
Rulon A	400-500 (.080" thick)	2.6	10^{15}	Dixon Corp.
ADHESIVES				
Epon 840	400-500	4.6	5×10^{15}	Shell Chemical Co.
Scotchcast 504	450	4.33	12×10^{14}	3M Company
Scotchcast Resin	450	4.3	$> 10^{14}$	3M Company
Viton	500	- -	2×10^{13}	DuPont
Silastic 732 RTV	500	2.8	1.5×10^{13}	Dow Corning
Stycast 3070	500	4.2	2×10^{16}	Emerson Cumings
Skybond 700	179	4.1	1.9×10^{7}	Monsanto
Eccobond 98	450	4.0	10^{16}	Emerson Cumings
Eccoseal W66	500	3.2	10^{15}	Emerson Cumings
Polyurethanes	5600	4.3	10^{16}	Columbia Technical Corp.
GASES				
Air (1 atm)				
ball electrode	100 (.100 thick)	1.0	- - -	Reference Date for Radio Engineers
needle electrode	33 (.100 thick)			

PROBLEM AREAS AND FUTURE REQUIREMENTS OF ELECTRO-EXPLOSIVE DEVICES

by

Dan Waxler

Session II of the Fifth Symposium on EEDs was entitled "Problem Areas and Future Requirements." The topics covered were chiefly devoted to the problems of hazards and interference from electromagnetic energy. The energy is that due to transmitters, lightning, and electric static discharge.

The first paper, by Robert M. Price, U. S. Naval Weapons Laboratory, was a description of that laboratory, and specifically, of its activities in the HERO Program. HERO is charged with the responsibility of determining the degree to which weapons may be susceptible to electromagnetic radiation, of devising means and techniques for rendering weapons safe in radiation fields, and for recommanding operational and handling restrictions as a temporary remedy to the problem until permanent methods are available. The Electromagnetic Hazards or HERO Division at Dahlgren has about one hundred people actively engaged. The Ship Systems Command which you probably know better by its former name, Bureau of Ships, has specified the magnitude of the electromagnetic fields on the decks of ships. The Naval Weapons Laboratory must determine the susceptibility of all Navy equipment containing EEDs subjected to these fields. To do this, complete weapon systems are exposed to RF environment in unique facilities. The facility at Dahlgren is a steel deck, 4 feet long by 100 feet wide, designed to simulate an aircraft carrier deck. At one end there is a turntable capable of rotating loads up to 25 tons. There are radio and radar transmitters to create the RF fields for the tests. HERO tests have also been conducted at the Naval Air Test Center, Patuxent River and on board ships of all types. The test must be on the complete weapon system including delivery system for air-launched weapons.

In the test, a weapon is inert except for live EEDs for go no-go tests and an EED simulator for instrumented tests. Go no-go tests indicate whether there is an actuation, nothing more. An instrumented test tells how close they have come to actuation. If a weapon is found susceptible, either restrictions must be placed on RF transmission or the weapons must be hardened.

The ideal solution is to thoroughly design a weapon to be immune to electromagnetic radiation. The approach is illustrated in Figure 3. Here all EEDs and their associated circuits are completely enclosed within a conductive shield. This precaution is sometimes not possible so the technique of Figure 4 must be resorted to, wherein components are placed in individual shielded compartments and interconnected by shielded wiring.

Where such over-all shielding is not feasible, as where electric firing signals are derived from a remote source, a suppression device, illustrated in Figure 5, a low-pass electric filter, is installed in the transmission line and the circuit shielded from the output of the filter through the EED.

Not only is there a problem due to radio transmission but also arc discharges can be hazardous. These occur during interface connections. Suppression devices as illustrated will not protect against such discharges since they contain low-frequency energy similar to that furnished by the firing source. One solution to this problem is to open a firing circuit between the arc and the EED until after the connection is made as shown in Figure 6.

The design approaches used are described more thoroughly in the HERO design guide which is available to weapon designers and developers.

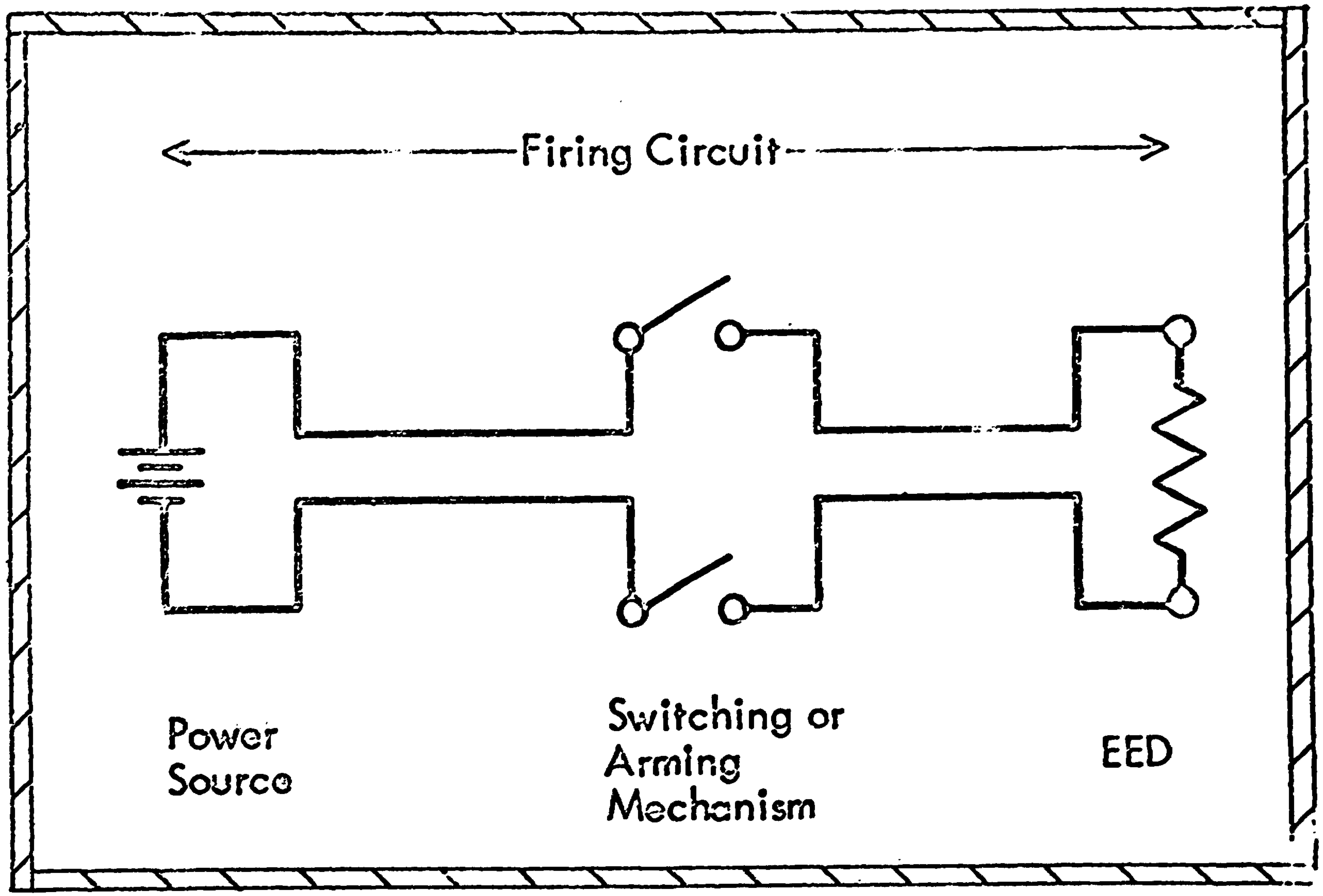


FIG. 3 THE CONDUCTIVE BOX CONCEPT

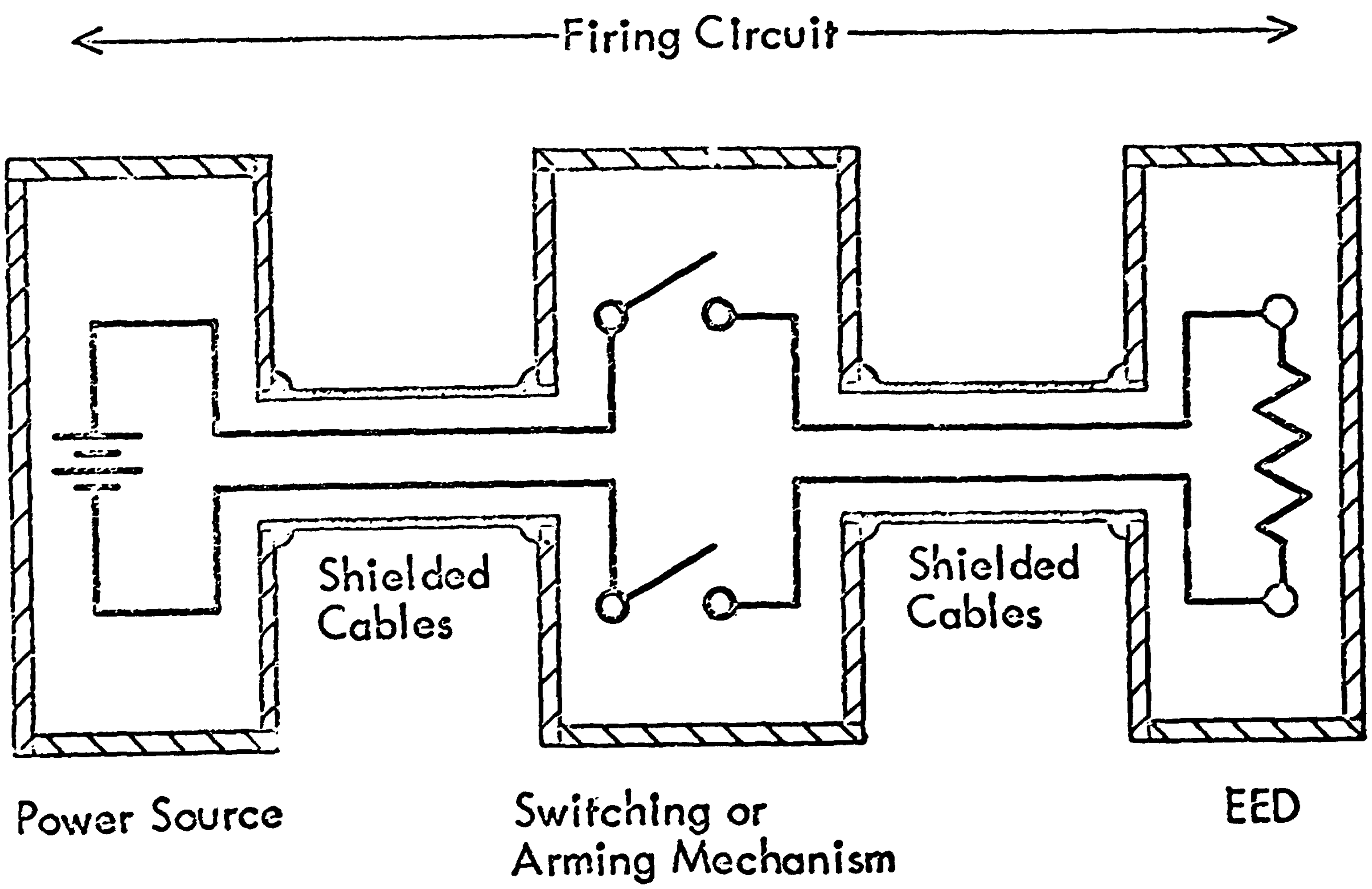


FIG. 4 COMPARTMENTALIZATION, AND SHIELDING OF COMPARTMENTS AND CONNECTIONS

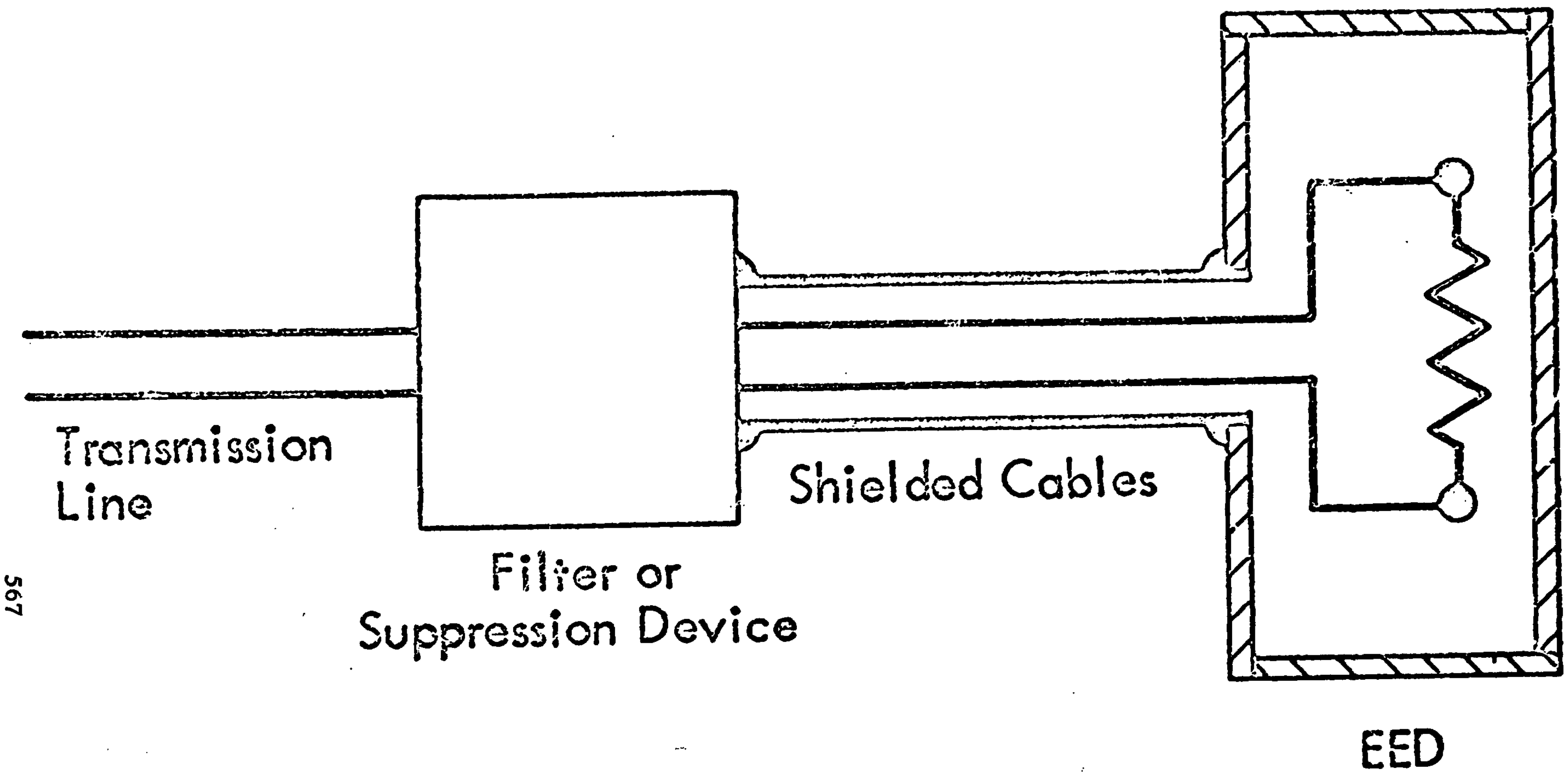


FIG. 5 USE OF RF FILTER OR SUPPRESSION DEVICE

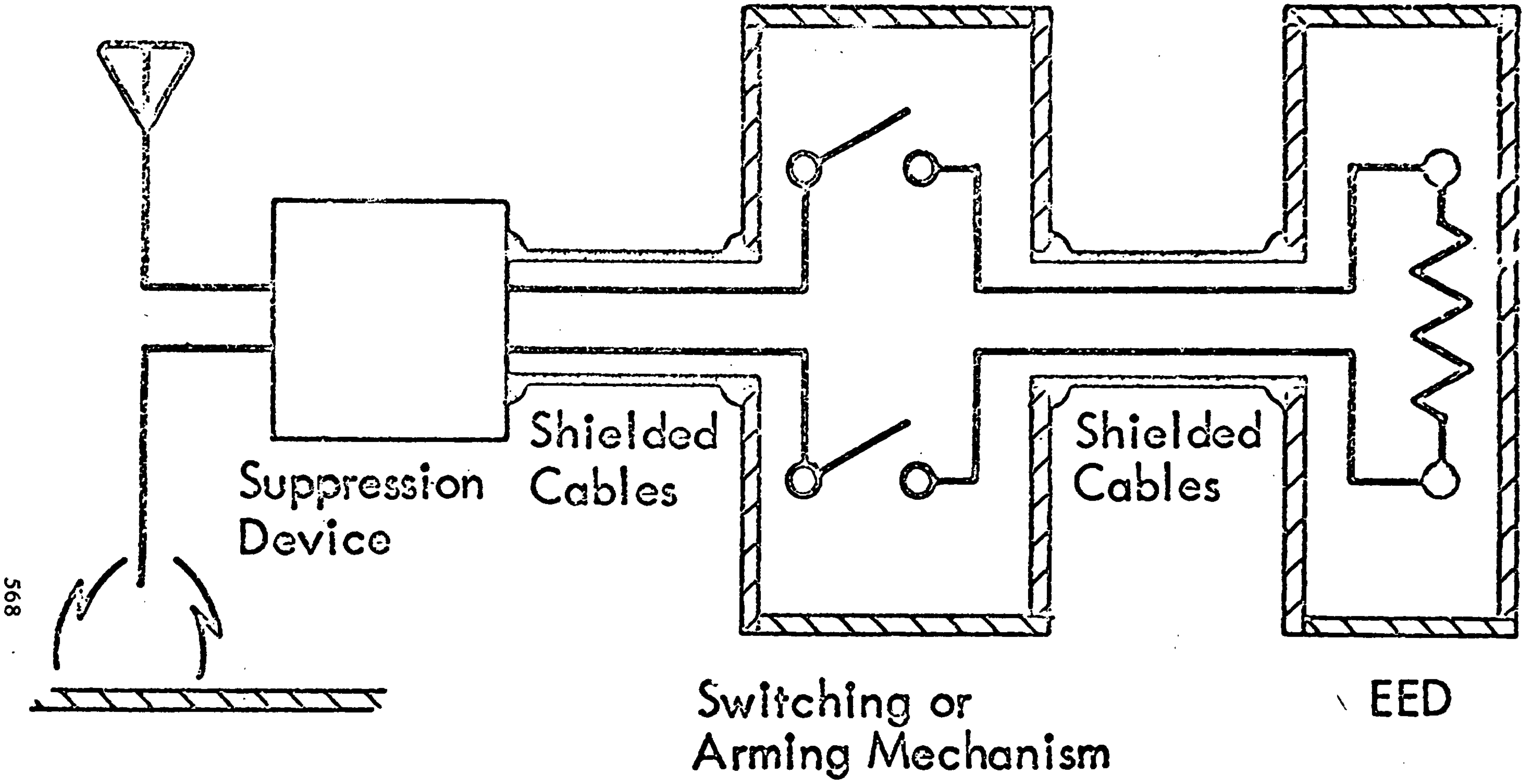


FIG. 6 A BASIC SOLUTION TO THE ARCING PROBLEM

The second paper entitled "Radio Frequency Interference Protection for Pyrotechnic Systems and Related Aircraft" was by Robert L. Robinson of NASA Manned Spacecraft Center. This paper describes techniques employed to reduce the hazard of radio frequency interference to EEDs in spacecraft.

The Apollo Spacecraft uses a standard EED for ignition in all explosive functions. There are two devices, one with a double bridge wire and the other with a single bridge wire. The presentation was only on the double bridge wire and is illustrated in Figure 1a. The all-fire rating is 3-1/2 amperes, while the no-fire calls for 1 watt dissipation for 5 minutes for each bridge wire. Pin-to-case requirement is that 9,000 volts can be discharged from a 0.0005 microfarad capacitor.

From a study made by the Manned Spacecraft Center the following table indicates the significant RF emitting sources in the spacecraft mission.

Equipment	Frequency, MHz	Field Strength, watts/meter^2
Ground stations	6000	20
Shipboard	4000	80
Emitters onboard spacecraft	3000	30

Figure 2 is a simplified envelope of the worst environment expected in Figure 1b. The electrical configuration of the initiator is illustrated. The dash lines represent the metal case of the unit. Of concern is that ignition could occur if sufficient voltage were emplaced between the pins and the case. Extensive testing has shown that the energy required for this ignition mode (as opposed to bridge wire heating) is much less. After testing, the initiator seemed to be most sensitive at 9 GHz where the no-fire level (1 in 1000 fire) was 89 milliwatts.

To prevent premature firing due to RFI an isolated and shielded system was used. Figure 3 shows the techniques employed. Each EED circuit obtains power from its own battery and is completely enclosed within a shield. The circuit is balanced and isolated from the spacecraft structure except for the high value electric static field resistor. All the wiring outside the metallic relay boxes consist of twisted shielded pair cable. The systems have been able to meet a requirement of 40 DB of RFI power attenuation.

For more advanced and longer duration spacecraft mission, a different approach is being followed. This approach is an RFI filter in the electric circuit just ahead of the EED. This method is attractive because the expected RF environment is at high frequency where small lossy filters become effective. In long duration missions, the EED electric system can no longer have its own power supplied but must be powered from the spacecraft's main power systems. As a result, circuit isolation cannot be employed with a filter. The main spacecraft power source can be used for initiation and still achieve the required circuit isolation at the RFI frequency involved.

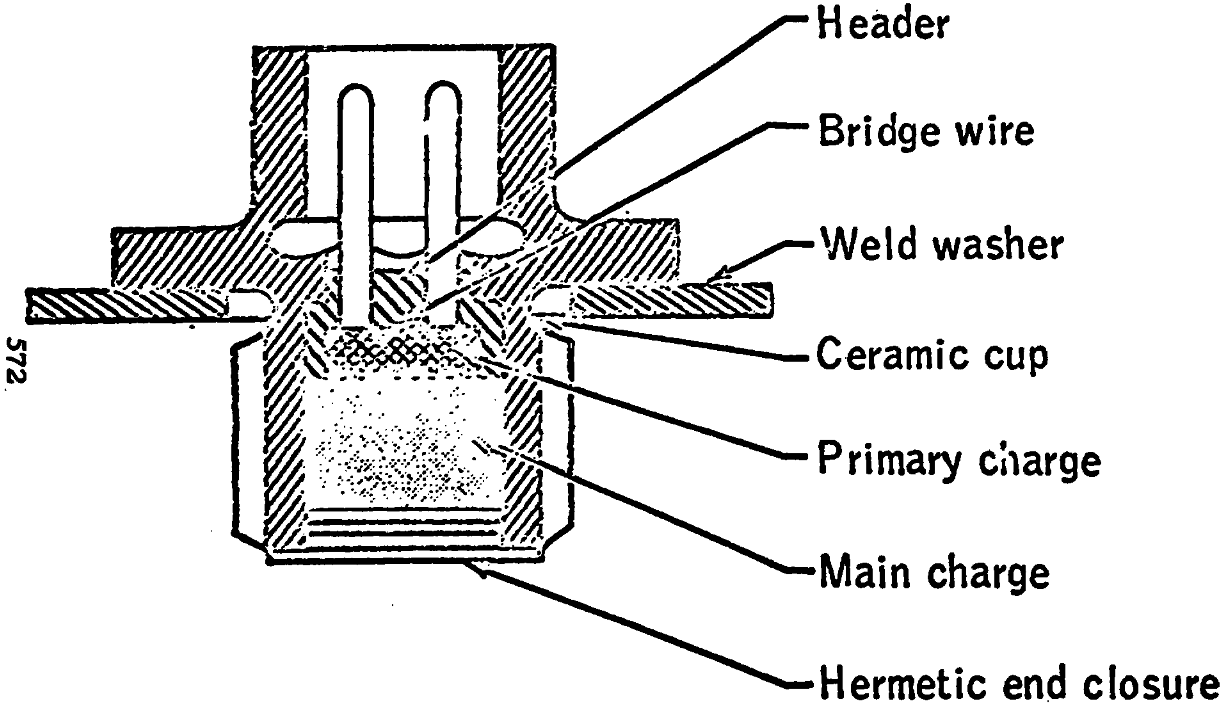
A number of advantages are claimed for using a filter instead of shielding. A weight savings of more than 1000 pounds could have been made by eliminating the shielding system on the Apollo Spacecraft and using a filter instead. The greatest advantage is that the attenuation of a filter is easily measured. A program was initiated to survey industry's ability to supply a suitable unit. Reliability and attenuation were a large factor in the selection of a filter. Other factors were attenuation of the normal EED firing pulse, power capacity, voltage breakdown, and the effect of the filter upon monitoring the bridge wire. Weight, cost, and size are also factors.

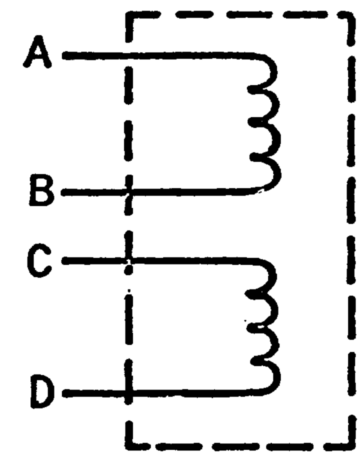
Thirty-two systems were analyzed in the filter survey culminating in the selection of a hybrid type shown in Figure 4a. The filter is a combination of an LC filter and ferrite beads. The LC filter rejects high frequency signals. At higher frequencies, the elements no longer are pure L and C and become useless at these frequencies. The ferrite bead dissipates high frequency power in the form of heat. The unit was constructed as shown in Figure 4b. It consists of four ferrite and coil assemblies.

The attenuation characteristics of the filter are shown in Figure 5. Figure 6 is a plot of the RFI environment with the same effective environment as attenuated the filter.

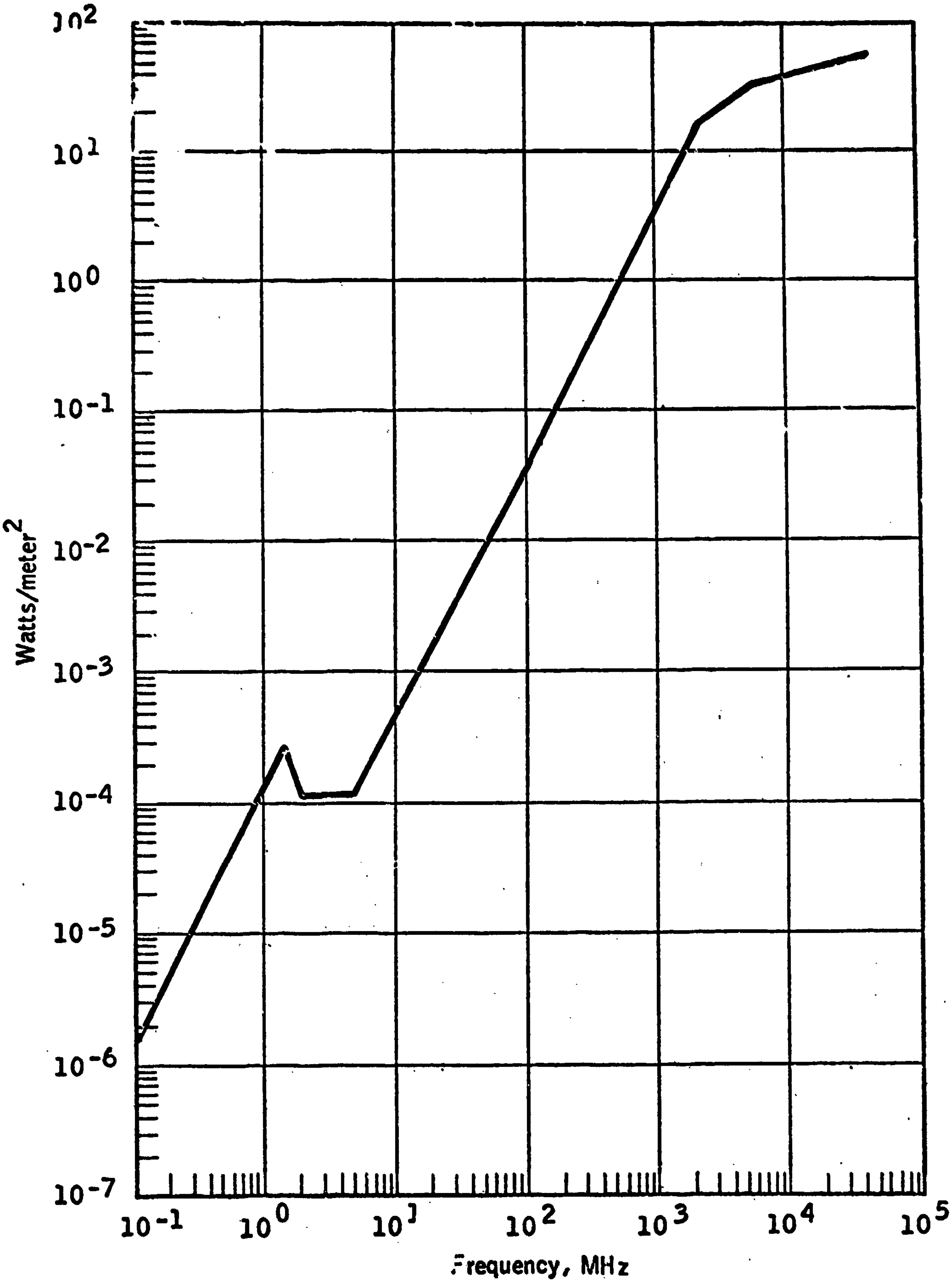
Twelve developmental devices have been constructed for testing. No problems were found throughout the test. The only failure that appeared was that of a soldered end closure. This problem can be corrected by welding the ends of the units.

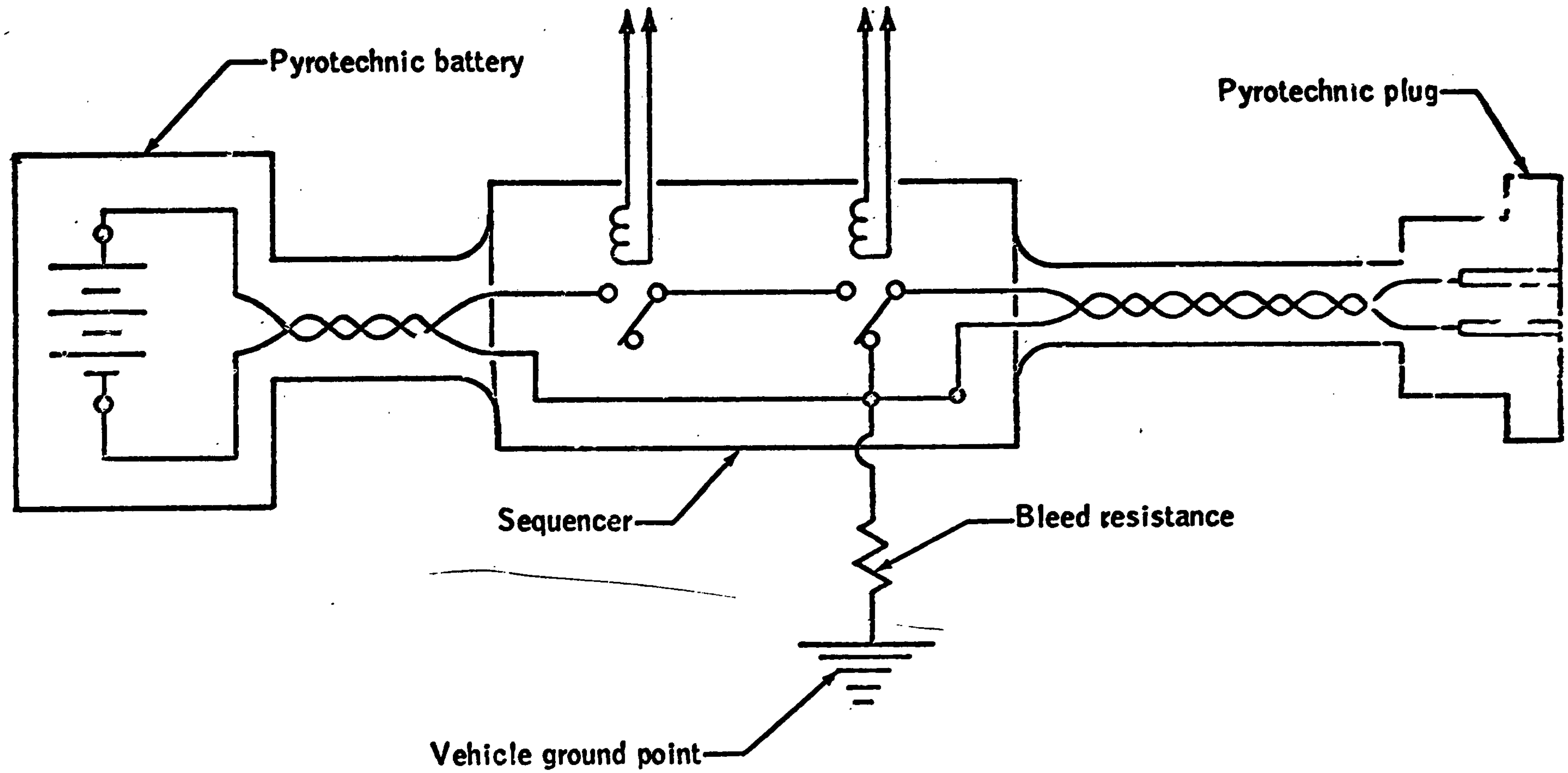
FIGURES

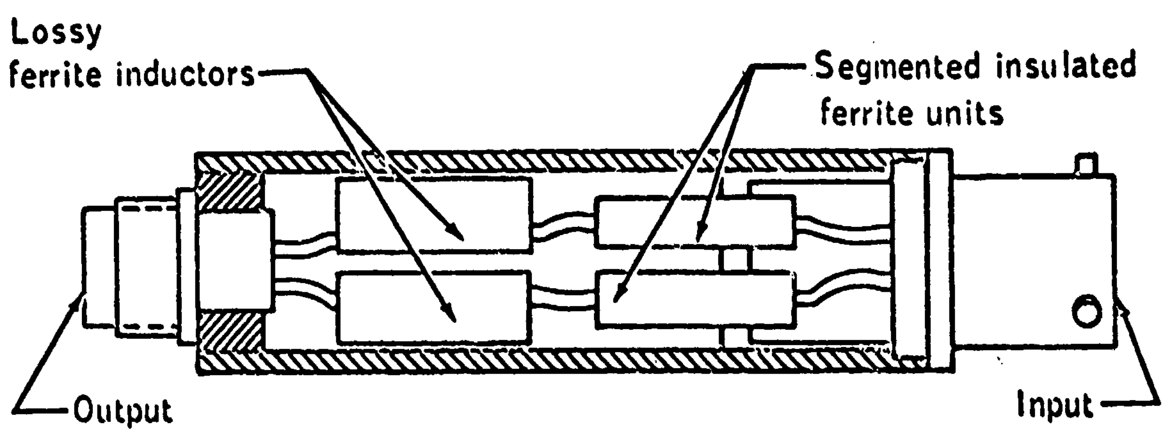

Header
Bridge wire
Weld washer
Ceramic cup
Primary charge
Main charge
Hermetic end closure

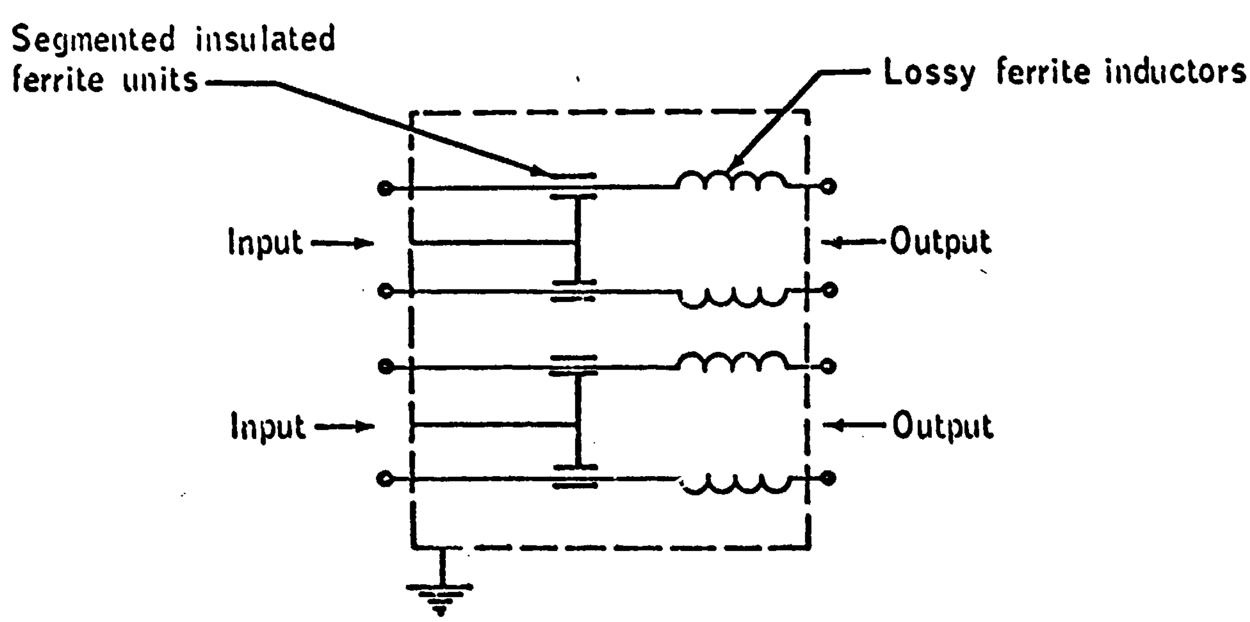

A
B
C
D

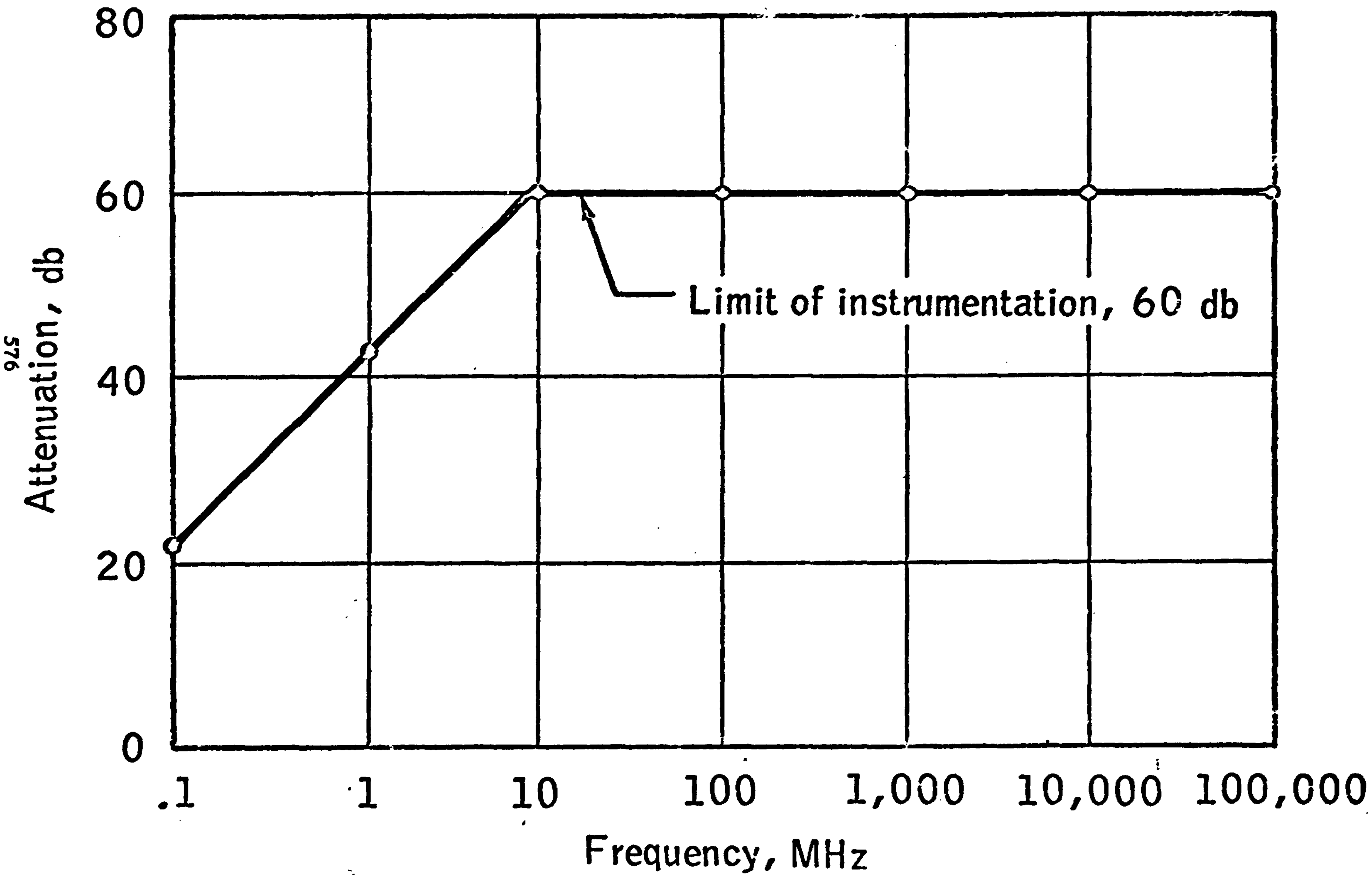
572


10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
Watts/meter^2
10^-1
10^0
10^1
10^2
10^3
10^4
10^5
Frequency, MHz

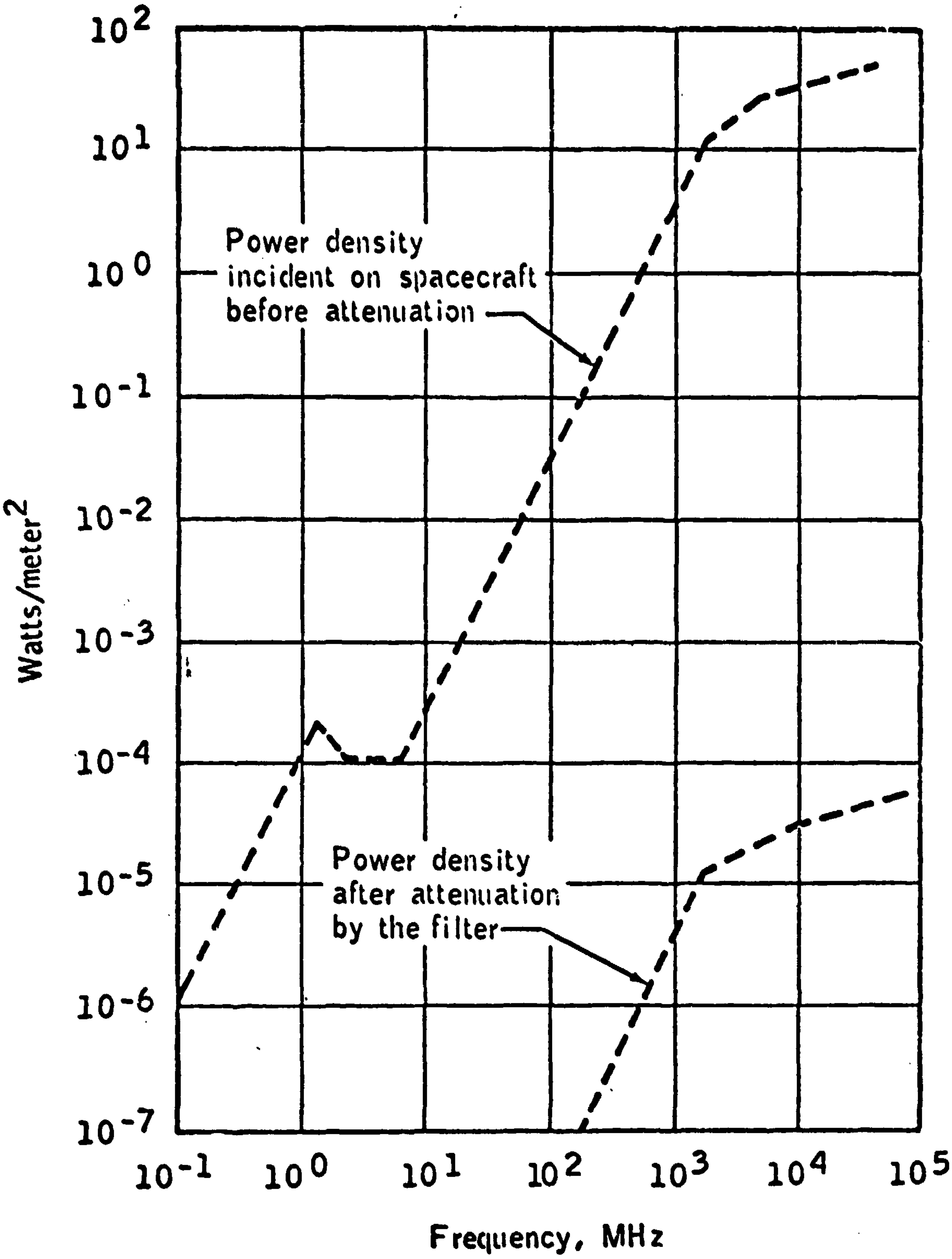

Pyrotechnic battery
Pyrotechnic plug
Sequencer
Bleed resistance
Vehicle ground point


Lossy
ferrite inductors
Segmented insulated
ferrite units
Output
Input


Segmented insulated
ferrite units
Lossy ferrite inductors
Input
Output
Input
Output



80
60
40
20
0
Attenuation, db
Limit of instrumentation, 60 db
.1
1
10
100
1,000
10,000
100,000
Frequency, MHz


Power density
incident on spacecraft
before attenuation
Power density
after attenuation
by the filter
Watts/meter^2
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-1}
10^0
10^1
10^2
10^3
10^4
10^5
Frequency, MHz

The third paper by Robert B. Cowdell, Genisco Technology Corporation, Genisitron, was entitled "Measuring the Electric and Magnetic Components of the Near Field," was not furnished me so that I cannot give you an extensive summary of it. The need for measuring in the near field is quite important but unfortunately it is quite difficult. The need for this measurement arises because of frequent location of weapon systems in the near field of transmitters. Near field can be defined as extending to about one wave length from the antenna. It should preferably be called the "induction zone" because of confusion in the definition of the near field between radio and radar engineers. In the induction zone, electric and magnetic fields are not orthogonal nor are they simply related to each other as in the radiation field. Difficulty in measurement arises because the levels are easily upset by placing instrumentation therein.

Mr. Cowdell described techniques for minimizing the perturbation effects from the meter and for preventing the strong field from entering the meter except through probe antennas.

The fourth paper "Lightning Surge Current Hazards to Semi-Conductor and Electroexplosive Systems" was by J. D. Robb and J. R. Stahmann of the Lightning and Transients Research Institute. This paper describes an investigation to evaluate the mechanisms by which lightning effects penetrate into aerospace vehicles. The investigation includes the following hazards:

a. Hazards to EEDs from direct natural lightning strokes.

b. Possible hazards from HF electromagnetic field surges.

c. Coupling through aperture of transient pulsed microwave energy.

d. Miscellaneous practical coupling mechanisms.

These possible modes of energy coupling were studied along with the minimal pulse current magnitudes and time duration to fire EEDs.

A study was made of the RF current penetration of a hypothetical vehicle represented as an imperfectly conducting cylinder with closed ends. Penetration was calculated for several thicknesses of aluminum skin. The study showed that the electric field inside the cylinder would be due to the IR drop along the interior surfaces from the current that penetrated to the inside surface. A very small magnetic field could also be found inside because of the time rate of change of the field.

The principal problems seem not to lie in direct penetration of the excellent outer skin shielding but rather in the discontinuities or openings in the skin and the joints at which stroke voltage can enter

the electrical circuitry to EEDs. These joints include the following, each illustrated in the attached figures:

a. Ground return coupling across bonding or discontinuities.

b. Direct stroke penetration.

c. Induced streamering through antennas.

d. Inductive coupling of lightning stroke currents into aircraft wiring.

Bonding problems are becoming increasingly severe because of the increased vulnerability of semi-conductors and the even more serious concern with fuel systems. This concern should require a revision of present bonding specifications which are largely out of date.

It can be concluded that:

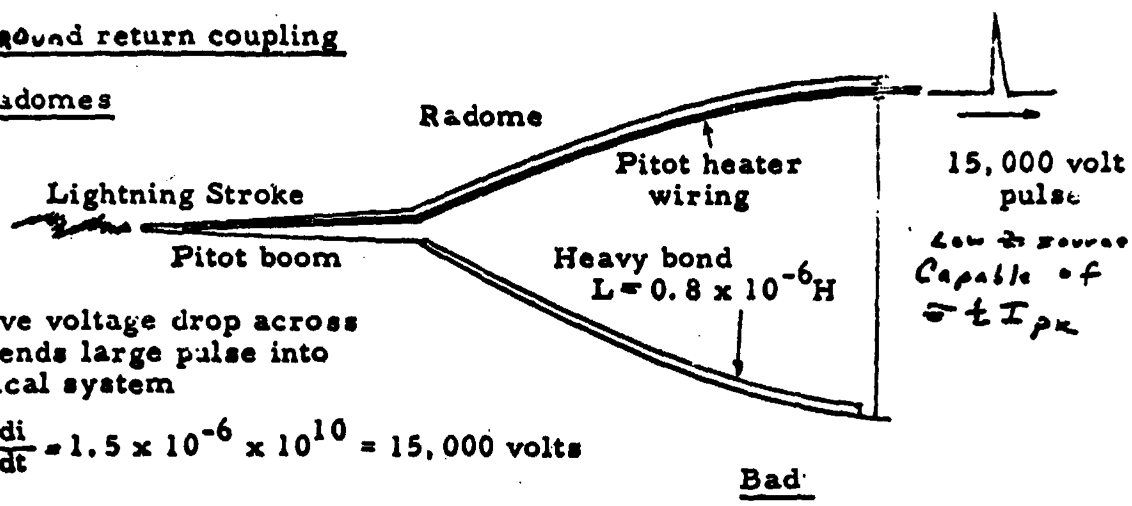
a. The pulse voltage penetrating the continuous outer metal skin of an idealized vehicle should be relatively small for even direct lightning discharges.

b. The practical aspect is that most penetration is through openings in the vehicle skin such as antenna, navigation lights, plastic sections, windows, and possible joints.

c. Vehicle skin joints previously evaluated for possible sparking for lightning discharge currents should be checked for pulse penetration.

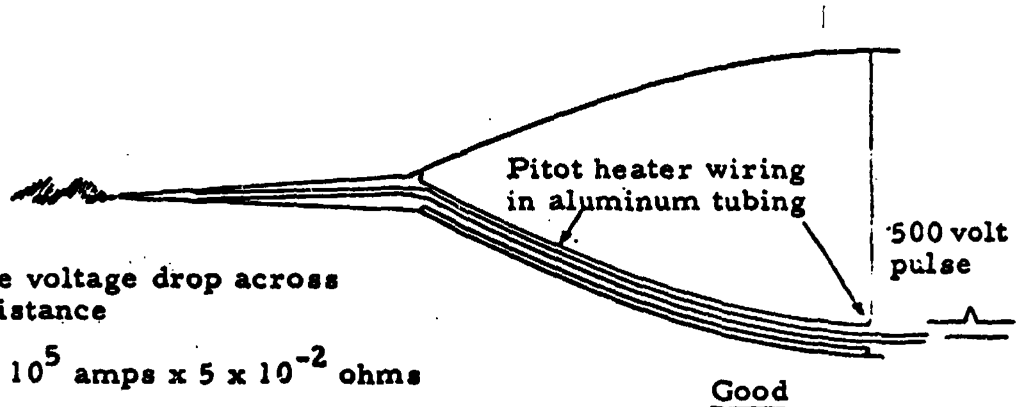
1. Ground return coupling

1.1 Radomes



Reactive voltage drop across bond sends large pulse into electrical system

$V = L \frac{di}{dt} = 1.5 \times 10^{-6} \times 10^{10} = 15,000$ volts

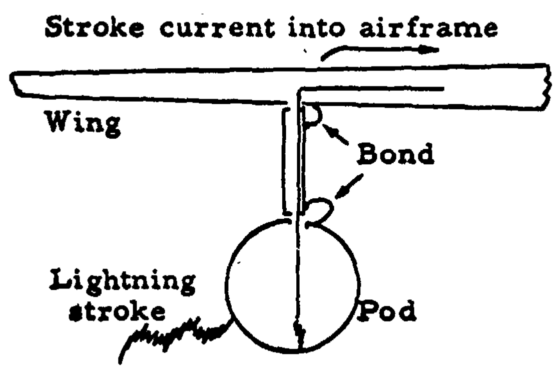


Resistive voltage drop across tube resistance

$V = IR = 10^5$ amps $\times 5 \times 10^{-2}$ ohms

$= 500$ volts

1.2 Pylon to wing bonding



Cround return coupled voltage into pod or pylon wiring - of the order of -

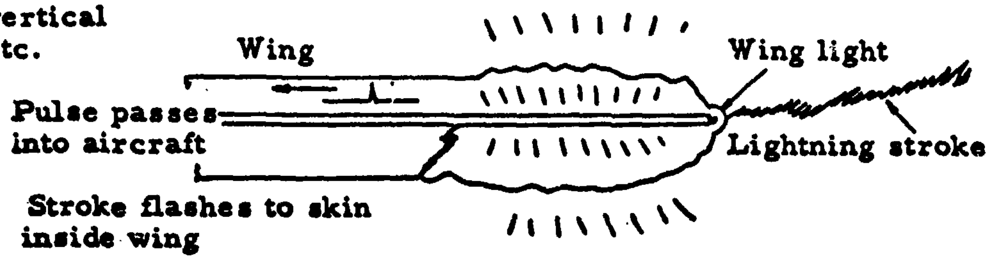
$V = L \frac{di}{dt} \approx 0.1 \times 10^{-6} \times 10^{10}$

≈ 100 to 1000 volts

2.0 Direct Coupling

2.1 Navigation light wiring

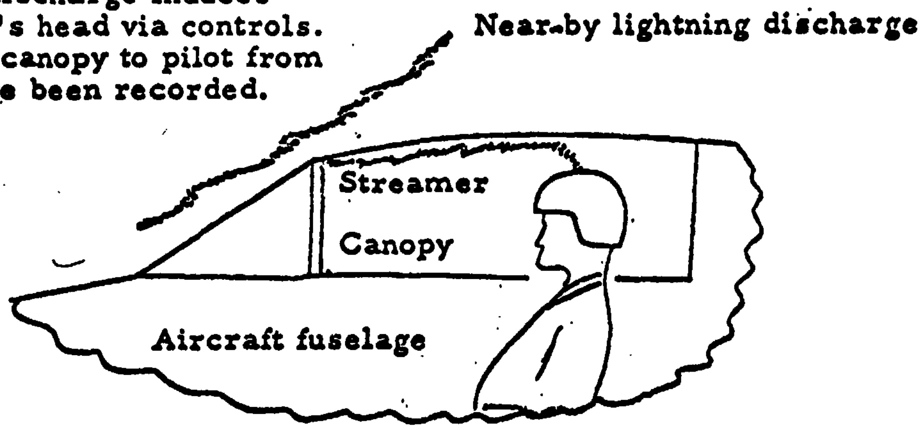
Direct structural hazard to wingtips, vertical stabilizers, etc.



3.0 Induced streamering inside plastic housing

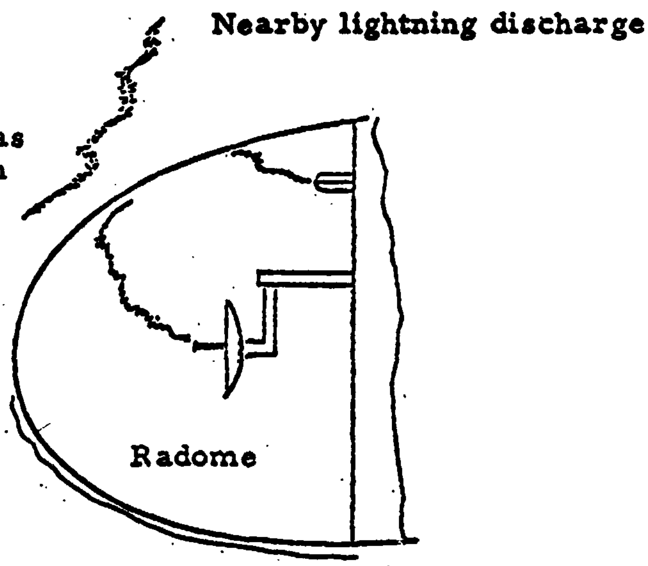
3.1 Canopy enclosures

Nearby lightning discharge induces streamer off pilot's head via controls. Note: Puncture of canopy to pilot from direct strokes have been recorded.



3.2 Radomes

Nearby lightning discharge induces streamers off antennas and wiring inside radome with or without puncture.

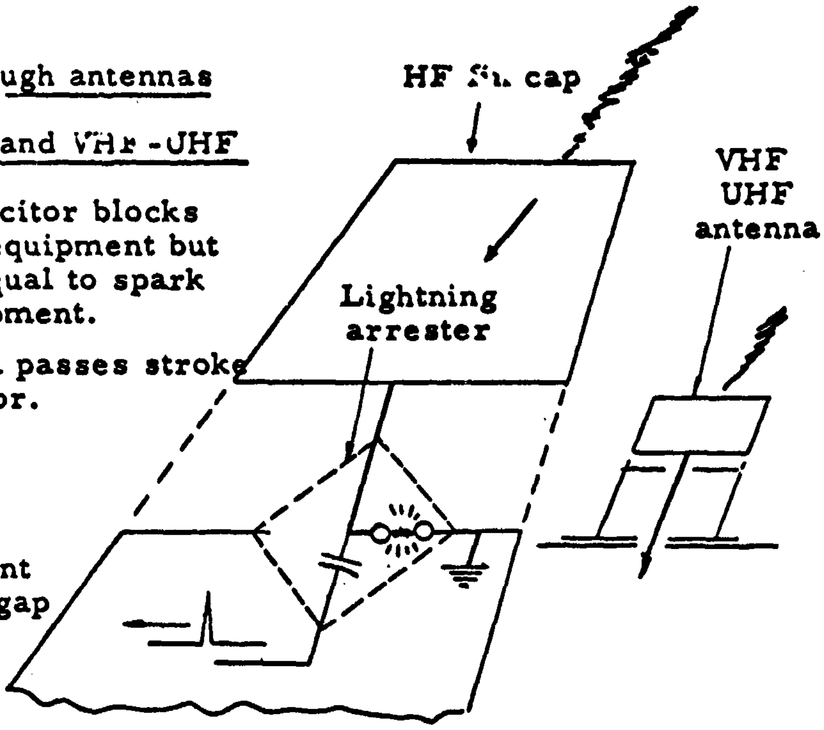


4.0 Surge penetration through antennas

4.1 Cap type antennas HF and VHF-UHF

HF lightning arrester capacitor blocks stroke energy from radio equipment but passes voltage transient equal to spark gap setting into radio equipment.

VHF-UHF cap type antenna passes stroke energy into aircraft exterior.

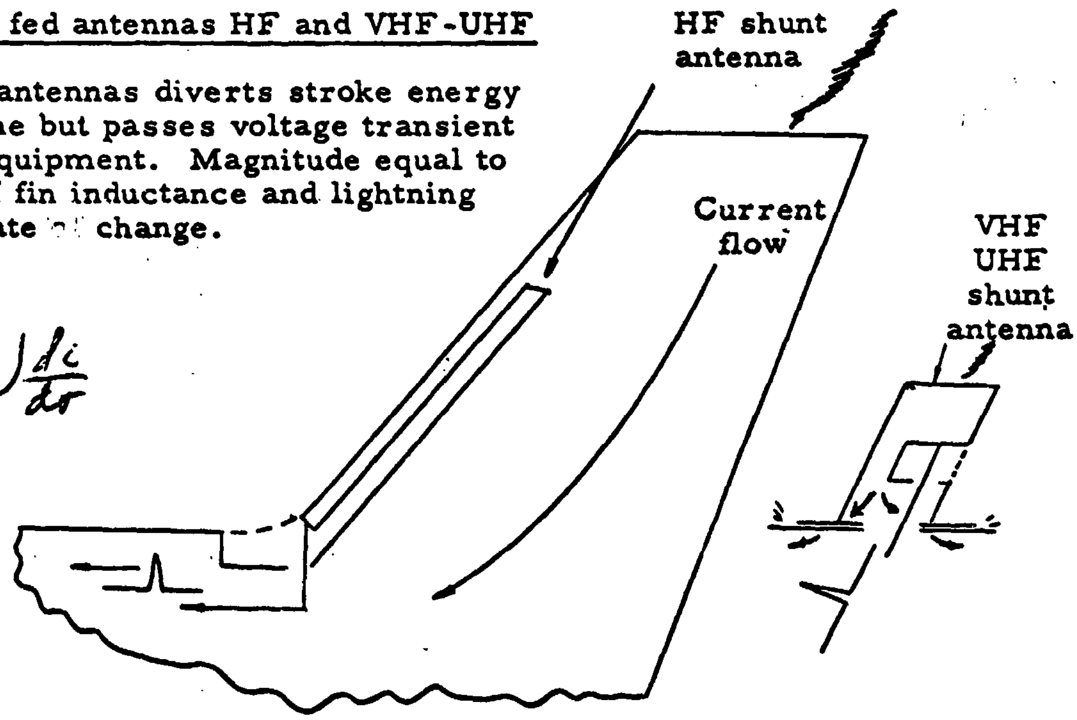


4.2 Shunt fed antennas HF and VHF-UHF

Shunt fed antennas diverts stroke energy to airframe but passes voltage transient to radio equipment. Magnitude equal to product of fin inductance and lightning current rate of change.

$V = \cancel{L\frac{di}{dt}}$

$(L-M)\frac{di}{dt}$



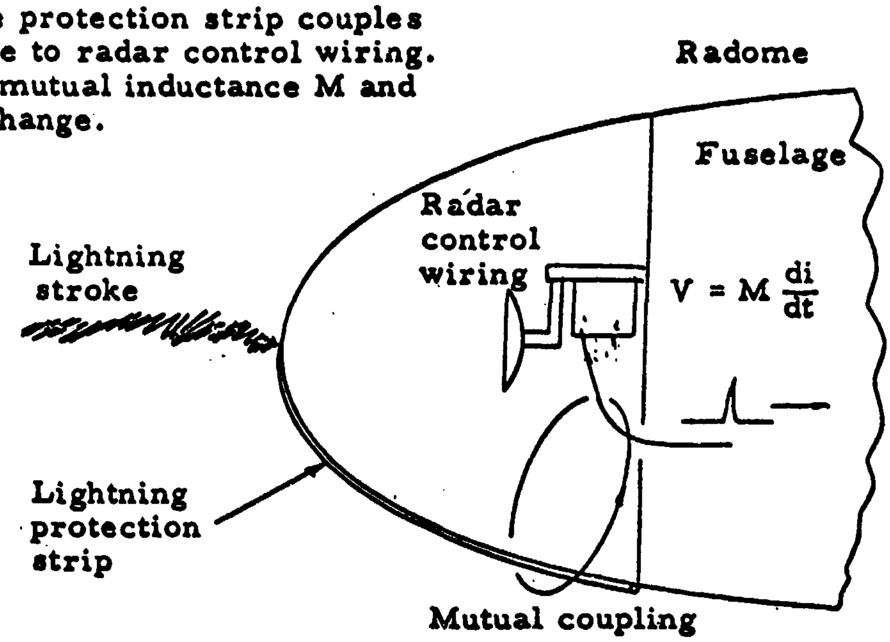
5.0 Mutual inductance surge coupling

5.1 Radomes

Stroke to radome protection strip couples high voltage pulse to radar control wiring. Voltage equal to mutual inductance M and current rate of change.

$$V = \cancel{M}\frac{di}{dt}$$

$$(L-M)\frac{di}{dt}$$

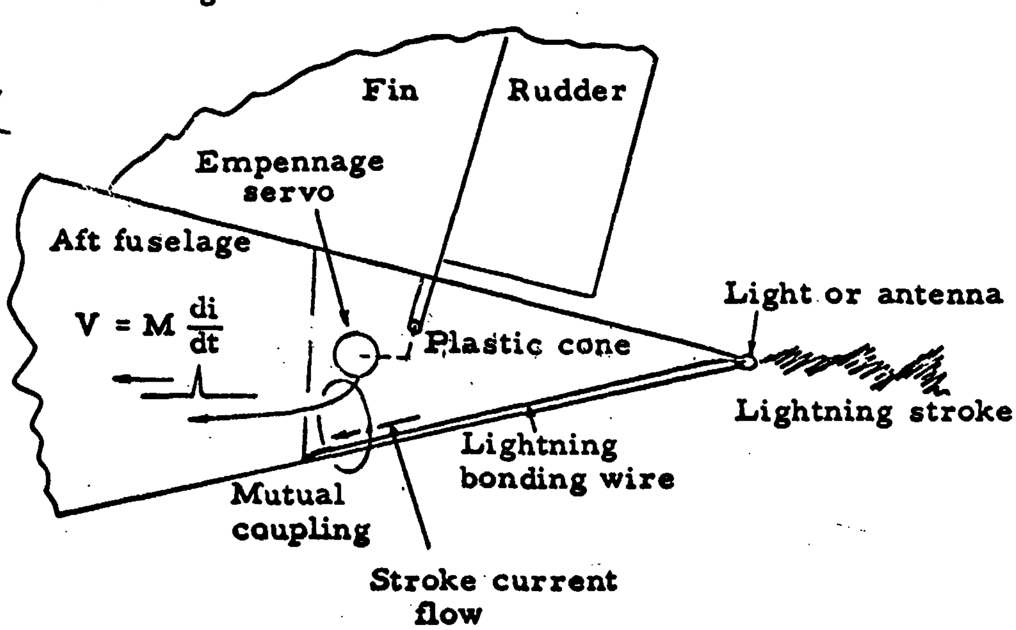


5.2 Empennage bonding

Flux coupling to servo motor control wiring product of mutual inductance and current rate of change.

$$V = M\frac{di}{dt}$$

$$V = (L-M)\frac{di}{dt}$$



The fifth and sixth papers were both concerned with electrostatic discharges, a subject of increasing interest, but unfortunately neither paper was made available to me. The seventh paper also on this subject was entitled "Designing Electro-Explosive Devices for Electrostatic Insensitivity" by L. D. Pitts, General Precision, Inc., Link Ordnance Division. This paper is an exhaustive one containing theory and design equations for analyzing EED designs for capability of withstanding a particular discharge from pin to case.

As indicated previously, EEDs are easily ignited by static discharge from pin to case. To illustrate the technique a simple configuration is shown in Figure 1 of a single homogeneous, symmetrical, dielectric block between two plate conductors. With a voltage applied between the plates, a uniform electric field creates the even distribution of equipotential surfaces in the dielectric. For an insulator, at low voltages, the current flow is trivial. When the applied voltage reaches the breakdown voltage, V_B, the insulator will begin to draw appreciable current. Normally, this consists of an arc in which electrons are pulled from their parent atoms into the arc beam. Presumably, this happens at some critical electric field intensity referred to as the dielectric strength, D, of the material. Thus, one might expect a linear increase in the breakdown voltage with increasing dielectric thickness. For most materials, however, the dielectric strength falls off rapidly with increasing thickness, as indicated in Figure 2. Dielectric strength may decrease by a factor of 10 as thickness varies from 1 to 100 mils. This behavior in solids is due to distance effects on the joule heating of the material by leakage current, according to Eichberger. However, others believe it is a result of statistical probability of avalanching, as in gases.

Other factors strongly influence dielectric strength measurements; electrode and insulator geometry, surface conditions, purity of materials, structural defects, environmental conditions (e.g., temperature, humidity, and pressure), and method of voltage application. For short time tests (as opposed to life tests), the common test voltages are impulse, AC and DC. Because impulse testing applies voltage stress for the shortest times, it generally produces the highest dielectric strength, often referred to as the intrinsic strength and considered the ultimate dielectric strength of a material. A lower dielectric strength is given by DC voltage, with AC still lower due to heating caused by the reversing motion of the electrons and ions in the changing electric field, or due to creation of space charge. The AC dielectric strength falls still further at high frequencies. However, tests for dielectric strength of air along an alumina surface indicate that step DC (discharge from a 500 pf capacitor) gives a dielectric strength of only 75% of that for slowly rising DC and peak value 60 Hz AC.

The remainder of this paper assumes that the applied voltage is a fast rising step, like the discharge of a capacitor into a high resistance.

A simple equivalent circuit (Figure 1) may be postulated for this configuration, a high resistance resistor in parallel with a low capacitance capacitor. If we apply a voltage step, the capacitor charges up instantaneously to the input voltage, and leakage current flows through the resistor. One could complicate the circuit by including the equivalent series resistance in the capacitor leg, but it is usually too low to have much effect on charging time of the capacitor.

In order to apply the criteria for breakdown of dielectrics to a specific EED design, it would probably be necessary to have better data on dielectric strength, permittivity, and resistivity of insulation materials than is presently available. To make the necessary calculations economically would require a computer program, so presently the author suggests the calculation of breakdown voltage across the likely paths in an EED design and use of applicable criteria in analysis of the design.

For instance, Figure 5 shows a hypothetical design of a hot-wire detonator. For simplicity, the bridge wire is not shown. First, one computes the breakdown voltage for each possible path.

$$V_{B(AB)} = D_{air} d_{AB} = (70 \text{ volts/mil})\ (25 \text{ Mils}) = 1{,}750 \text{ volts}$$

$$V_{B(AC)} = (250 \times 3)\ (25) = 18{,}750 \text{ volts}$$

$$V_{B(AD)} = (90)\ (20) + (70)\ (25) = 3{,}550 \text{ volts}$$

$$V_{B(AE)} = (90)\ (20) + (2{,}500)\ (3) + (110)\ (25) = 12{,}050 \text{ volts}$$

$$V_{B(AF)} = (90)\ (20) + (2{,}500)\ (3) + (110)\ (200) = 31{,}300 \text{ volts}$$

Dielectric strength values for explosives are taken from Table 1, values for other materials from Appendix A (70 volts/mil is a common approximation) for air. Tabulated value for thick steatite is multiplied by 3 per Appendix A instructions. From the section on series dielectrics, it is obvious we are not strictly correct if we consider only the summation of breakdown voltages across various paths. However, this turns out to be a useful first order approximation. Let us suppose we are working with a 9000-volt discharge from a 500 pf capacitor with no series resistor. It is obviously unlikely to arc through the ceramic at AC or, even allowing for decreased dielectric strength of RDX at 200 mils, along path AF. The presence of the teflon disc makes path AE an unlikely breakdown path. Path AB is intended to act as an external air gap to break down preferentially and prevent arcing through the primer. For AD, the dielectric strength of air is employed in the calculation across the top of the cup. Our experiments with a metal disc in place

of a primer show that unless an insulator is very carefully glued on the cup with a thick adhesive layer, the dielectric strength will be typical of air. Other experiments show that arcing easily occurs across a surface in air when an insulator is only 2 mils removed from the surface. Minimum gap distance may be much less.

Path AD is indeed the most likely failure mode for the short cup EED. In this case, of course, with the high spark sensitivity of lead azide, any arc through the primer will be sufficient to cause ignition. The ratio of $V_{B(AB)}/V_{B(AD)}$ is only 2 to 1 and the ratio of d_{AB}/d_{AD} less than 2 to 1. Also, $V_{B(AD)}$ is well below the peak 9000 volts applied and the arc resistance of AB across 25 mils of air is like to be somewhat higher than desirable. Thus, one might characterize this as a marginal device, one which would stand off 9 KV, by means of the external gap, but which would likely experience random failures. Filling gap AB with a high dielectric strength potting material would produce 100% failures. The simplest improvements to this design would be an increase in length and breakdown voltage of paths AD and gap is easily disabled in many cases by enclosing part of the pins with mylar tape for tubing and filling the gap with a high dielectric strength epoxy adhesive. With inerts in place of the explosive components, one can find the likely internal breakdown paths.

Preferably, protective gaps should be hermetically enclosed in the EED to prevent disabling of the gap by contaminants or mishandling. There are obvious tests to run to determine breakdown voltage and effectiveness of a gap. One may want to set up procedures to assure cleanliness and breakdown repeatability of a gap in a production.

Bridge wire Considerations - One wants to keep sharp corners and exposed points to a minimum, of course.

Electrostatic Insensitivity Specification - Specifications are inadequately written for electrostatic sensitivity testing of EEDs. A typical specification might read, "Shall not fire when 25 kV is applied from either pin to case from 500 pf capacitor through 5000-ohm series resistor." Such a loose specification may convince the designer that the customer is not very serious about the requirement and might buy off a lot which had a few test failures.

No tolerances on components or voltages are called out. Switching device and allowable voltage drop across it are unspecified. If a high voltage relay or spark gap is employed for switching, a keep-alive resistor is usually necessary to insure discharging the storage capacitor in a single repeatable pulse. The specification does not allow for this.

Since most EEDs breakdown in some manner, the specification should consider high frequency effects. However, there is no specification of rise time, so that a manufacturer's test system may be highly inductive, yielding slow rise time and lower peak currents. With long test leads to the EED, inductance and kin effect may absorb much of the voltage drop in the circuit and radiate a large portion of the energy stored in the capacitor. The customer should require measurement of voltage at the EED if he really intends the test voltage to be there.

Some initiators may be most sensitive with the 5000-ohm series resistor, but the bridge wire problems will not be tested since the resistor limits peak current to 5 amps. Some EEDs may pass a 25 kV test with flying colors, but fire at 5 or 10 kV, voltages they are more likely to see in the field, because the protective gap is less likely to fire first with a lower over voltage. It would usually be quite simple for the manufacturer to arrange for protective breakdown in his test equipment or output cable. The customer himself usually provides a protective device by specifying a connector that will not stand off the test voltage.

Even if there is no conscious cheating in electrostatic testing, the loose specifications and lack of standardization inevitably lead to confusing and misleading test results. Manufacturers are not going to take electrostatic sensitivity seriously unless forced to by adequate specifications or serious accidents. Until the customer learns to write a complete specification, he is going to continue to buy devices which are unsafe or at least not positively known to be safe.

TABLE 1

DATA PRESENTATION

(at approximately 20 mil thickness)

	Powder	Resistivity (Ω-cm)	Dielectric strength (volts/mil)	Density (gm/cm^3)
Primary Explosive	Normal Unmilled Lead Styphnate	10^{13}	140	2.5
	Basic Lead Styphnate	10^{14}	100	2.5
	Lead Styphnate with 2% Viton A	3×10^{12}	120	2.5
	Lead Azide	5×10^{10}	90	3.7
	75% Lead Azide 25% Lead Styphnate	9×10^{12}	130	2.5
Secondary Explosive	PETN	3×10^{12}	130	1.7
	RDX	5×10^{13}	110	1.5
	HMX	4×10^{10}	90	1.4
	HNS	5×10^{13}	400	1.5
Pyrotechnics & misc. mixes	Bullseye	4×10^{4}	< 5	- -
	Black Powder	10^{6}	< 5	1.6
	$BKNO_3$ Powder	3×10^{12}	70	.95
	80% PETN 20% Graphite	500	< 5	1.5
	PbO_2 - Al mix	3×10^{10}	< 9	4.3
	$KClO_4$ - Al mix	3×10^{3}	< 5	2.1
	$KClO_4$ - Zr mix	4×10^{10}	< 5	2.5

APPENDIX A

Insulation Properties

Table 1 of Appendix A lists insulation properties of materials culled from manufacturer's literature. Unless otherwise noted, the dielectric strength of the materials listed as header materials and adhesives appear to be for thick samples, while values for the insulation materials are for thin samples. Considering the relationship of dielectric strength vs thickness (Figure 2), one may arbitrarily raise the header and adhesive dielectric strength values for thin geometries (25 mils or less) by a factor of three. Values for insulation should probably be reduced by 5 for thick materials (greater than 25 mils).

APPENDIX A

TABLE 1

	Dielectric Strength V/mil	Dielectric Constant	Resistivity Ohm·cm	Source
HEADER MATERIAL				
Alumina 1510 (porous)	50 (1/4" thick)	5.5	10^{14}	Carborundum
Alumina 1542 96% (dense)	200 (1/4" thick)	9.2	10^{14}	Carborundum
Steatite 302	250 (1/4" thick)	5.58	-	Centralab
Boron Nitride	500	-	-	Union Carbide Corp.
Beryllia 7198	258	6.93	2×10^{14}	Frenchtown Porcelain
Glass Boro-silicate	1000	4.7	$> 10^{14}$	Corning Glass
INSULATION				
Mylar	4000	3.1	10^{19}	DuPont
Kapton	7000 (1 mil thick)	3.5	10^{18}	DuPont
Lexan	3910 (1.5 mils thick)	3.17	2.1×10^{16}	General Electric
Teflon	2500	2.0	—	Technical Fluorocarbon
Tedlar PVF film	3500	8.5		Technical Fluorocarbon
Scotchtite 3028	1400 (.010" thick)	5.3	30×10^{14}	3M Company
Rulon A	400-500 (.080" thick)	2.6	10^{15}	Dixon Corp.
ADHESIVES				
Epon 840	400-500	4.6	5×10^{15}	Shell Chemical Co.
Scotchcast 504	450	4.33	12×10^{14}	3M Company
Scotchcast Resin	450	4.3	$> 10^{14}$	3M Company
Viton	500	- -	2×10^{13}	DuPont
Silastic 732 RTV	500	2.8	1.5×10^{13}	Dow Corning
Stycast 3070	500	4.2	2×10^{16}	Emerson Cumings
Skybond 700	179	4.1	1.9×10^{7}	Monsanto
Eccobond 98	450	4.0	10^{16}	Emerson Cumings
Eccoseal W66	500	3.2	10^{15}	Emerson Cumings
Polyurethanes	5600	4.3	10^{16}	Columbia Technical Corp.
GASES				
Air (1 atm)				
ball electrode	100 (.100 thick)	1.0	- - -	Reference Date for Radio Engineers
needle electrode	33 (.100 thick)			

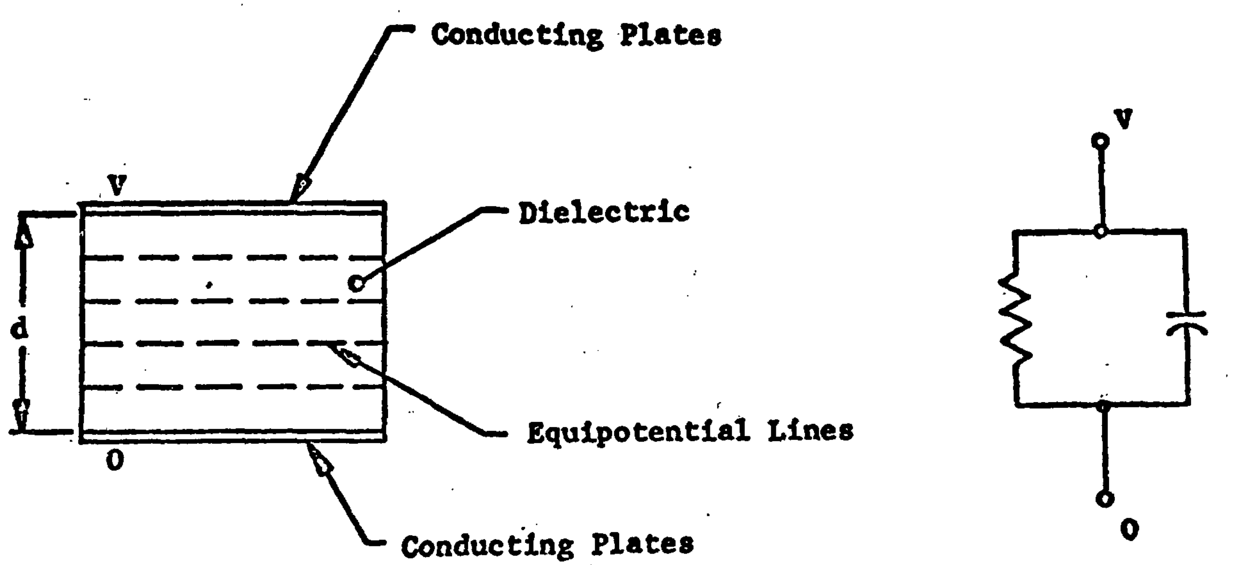


FIG. 1
SINGLE DIELECTRIC
SYSTEM

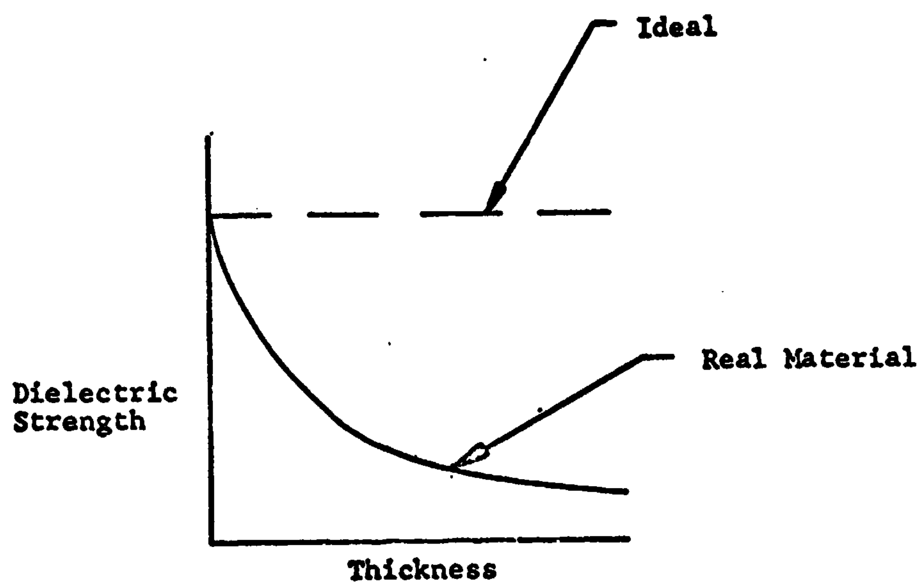


FIG. 2
GENERALIZED PLOT OF
DIELECTRIC STRENGTH VS
DIELECTRIC THICKNESS

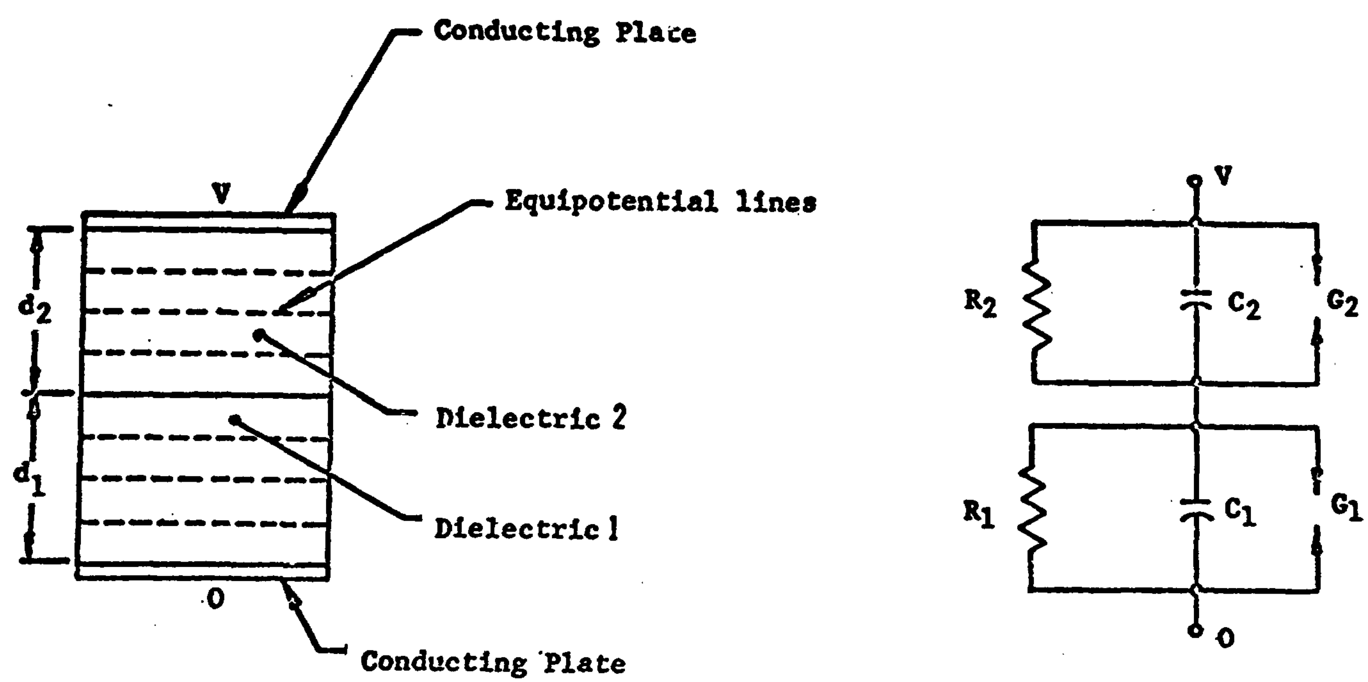


FIG. 3
TWO DIELECTRIC SERIES SYSTEM

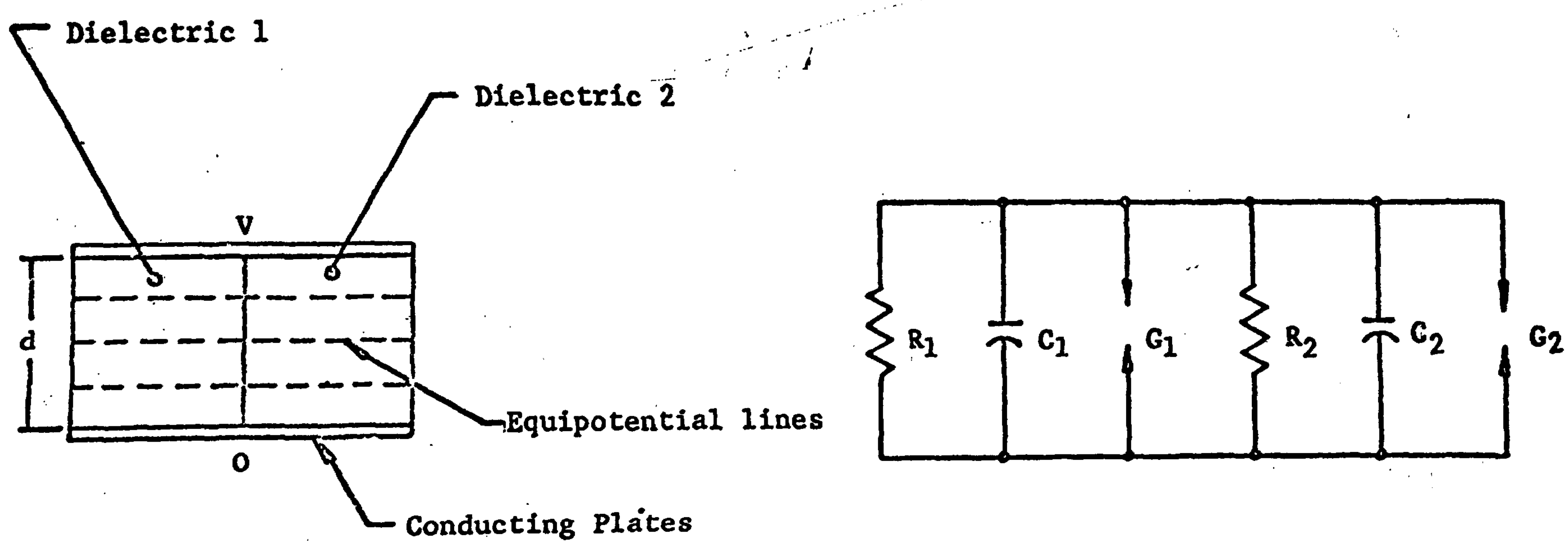


FIG. 4
TWO DIELECTRIC PARALLEL
SYSTEM

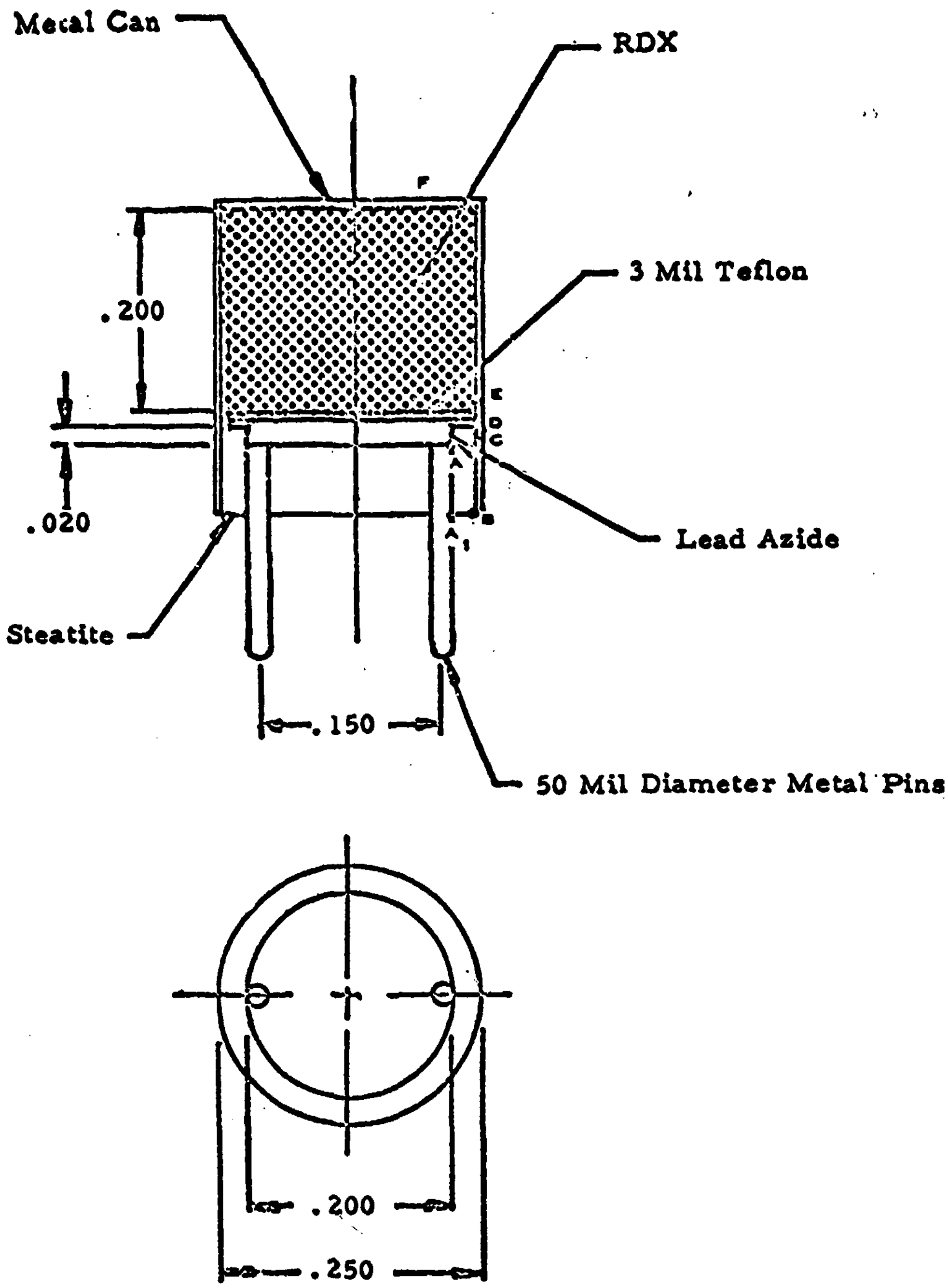
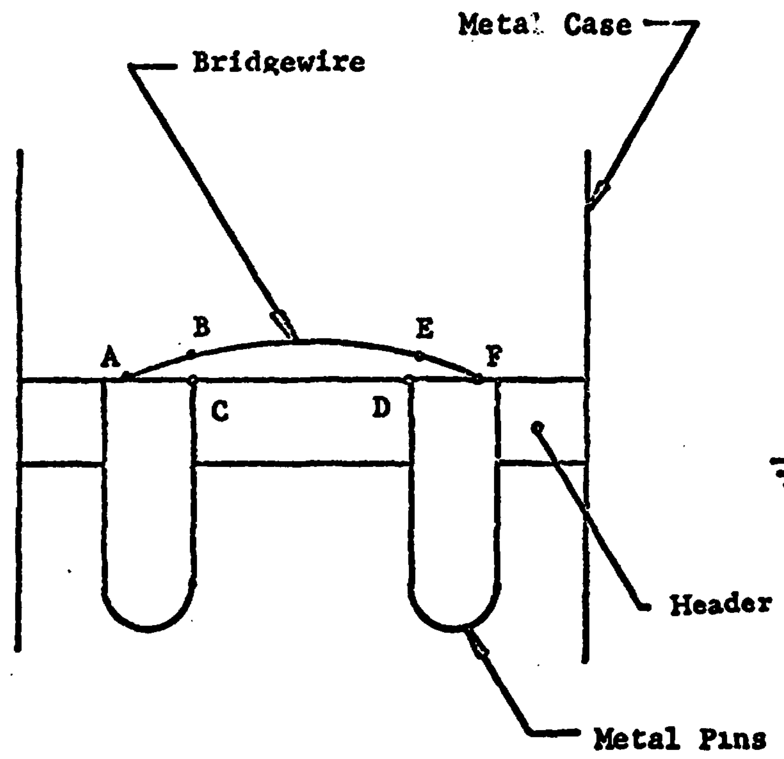


FIG. 5
HYPOTHETICAL DETONATOR DESIGN



Bridgewire System (bridgewire curvature exaggerated)

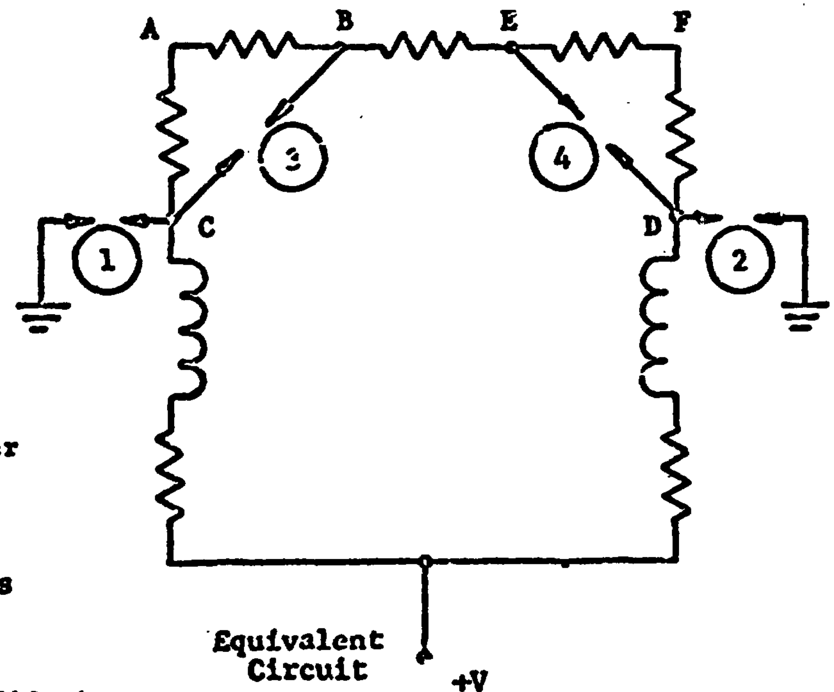
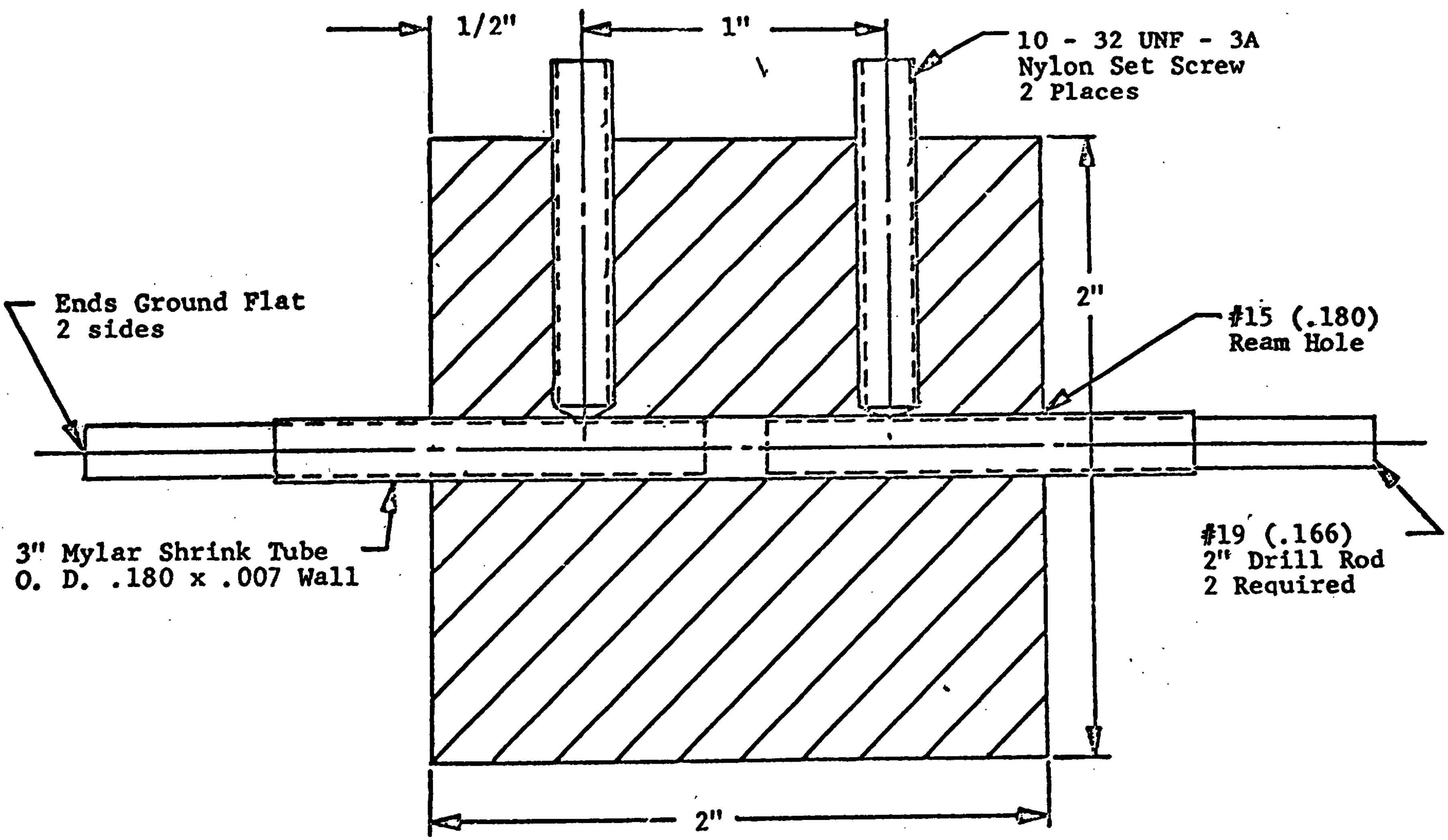


FIG. 6
BRIDGEWIRE SYSTEM UNDER STATIC DISCHARGE TEST



TEST FIXTURE
FOR
DIELECTRIC STRENGTH + RESISTIVITY TESTING OF EXPLOSIVES

FIGURE 7

Measurement of Dielectric Strength
and Resistivity of Explosives

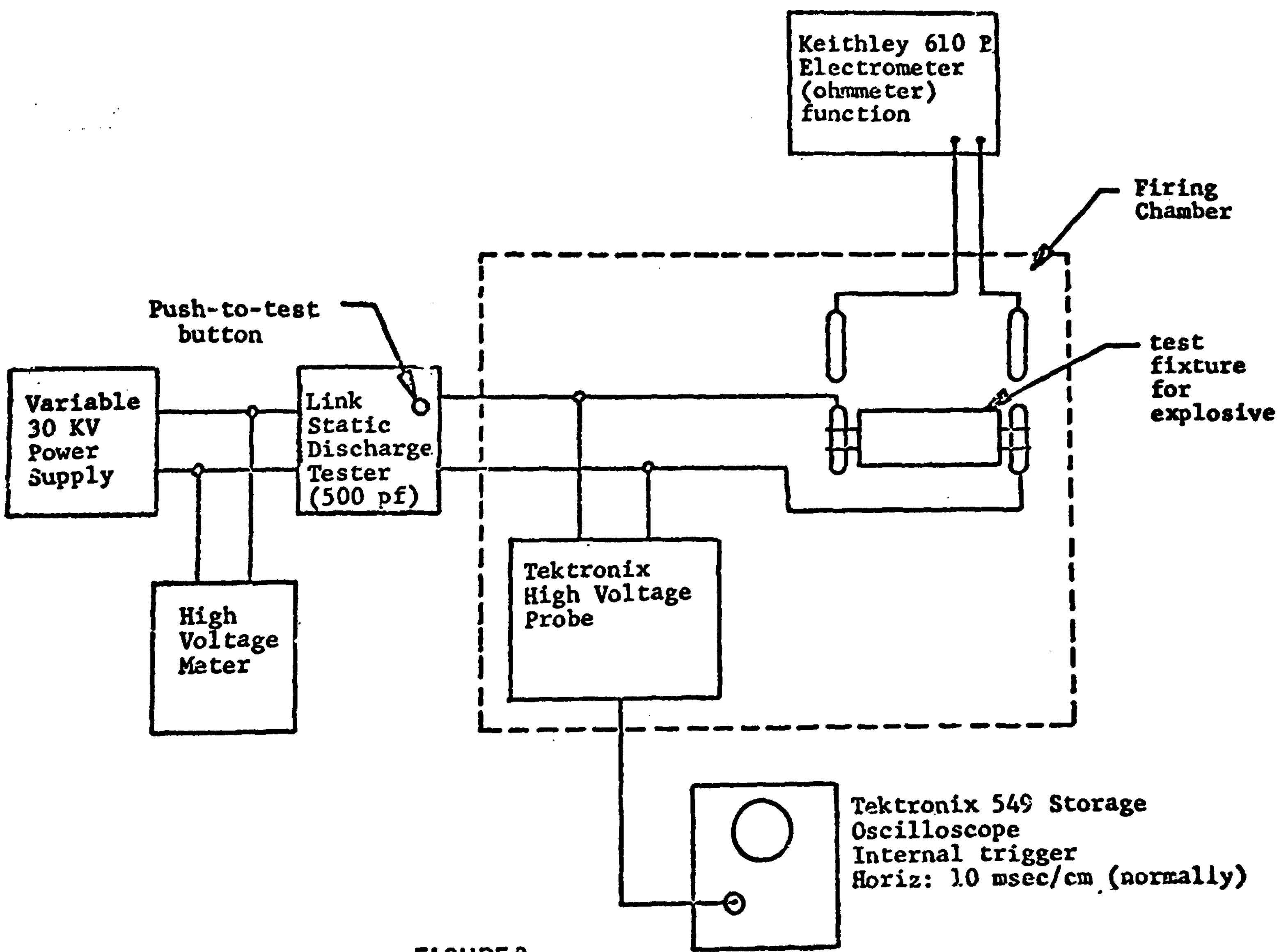


FIGURE 8

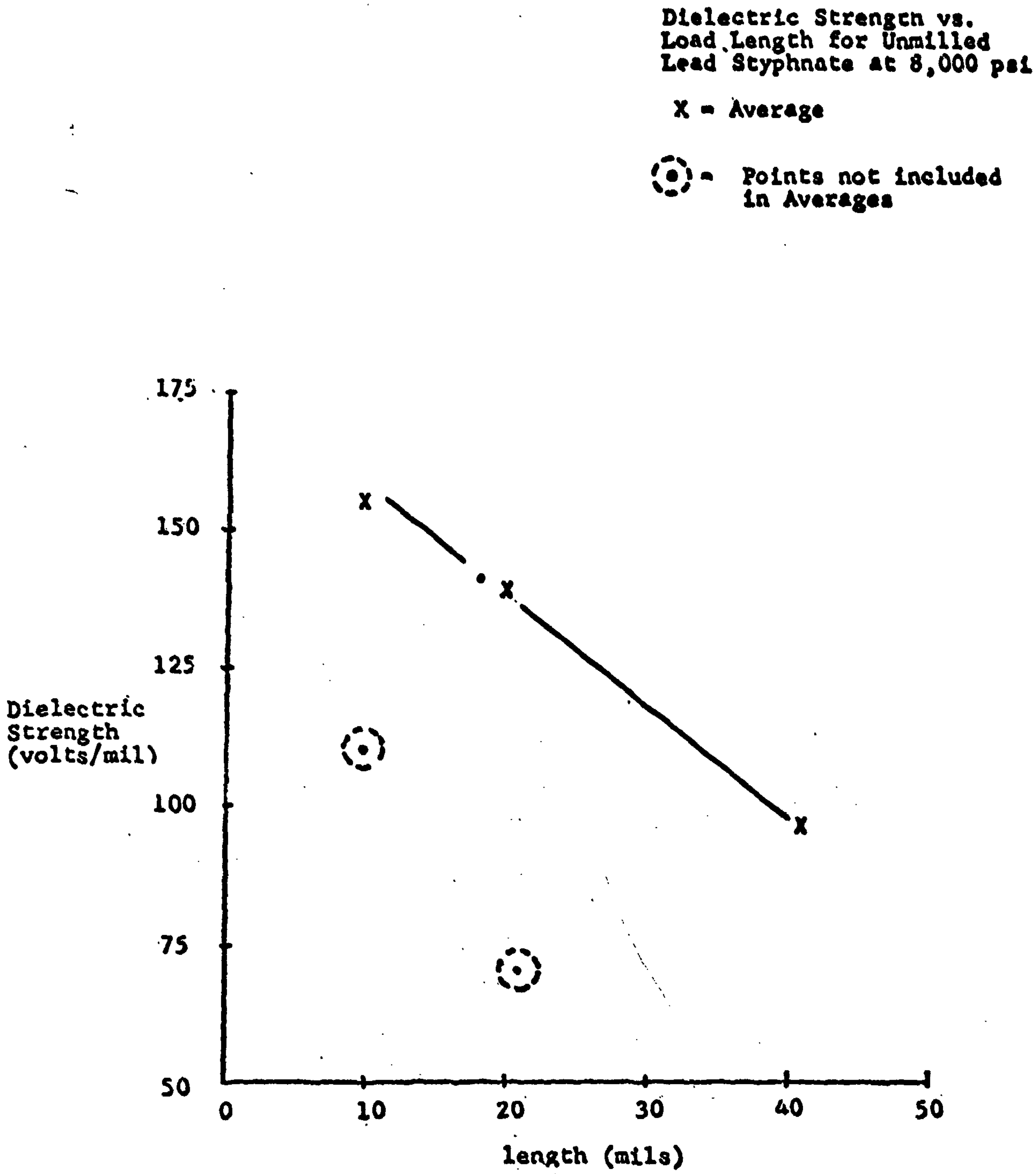
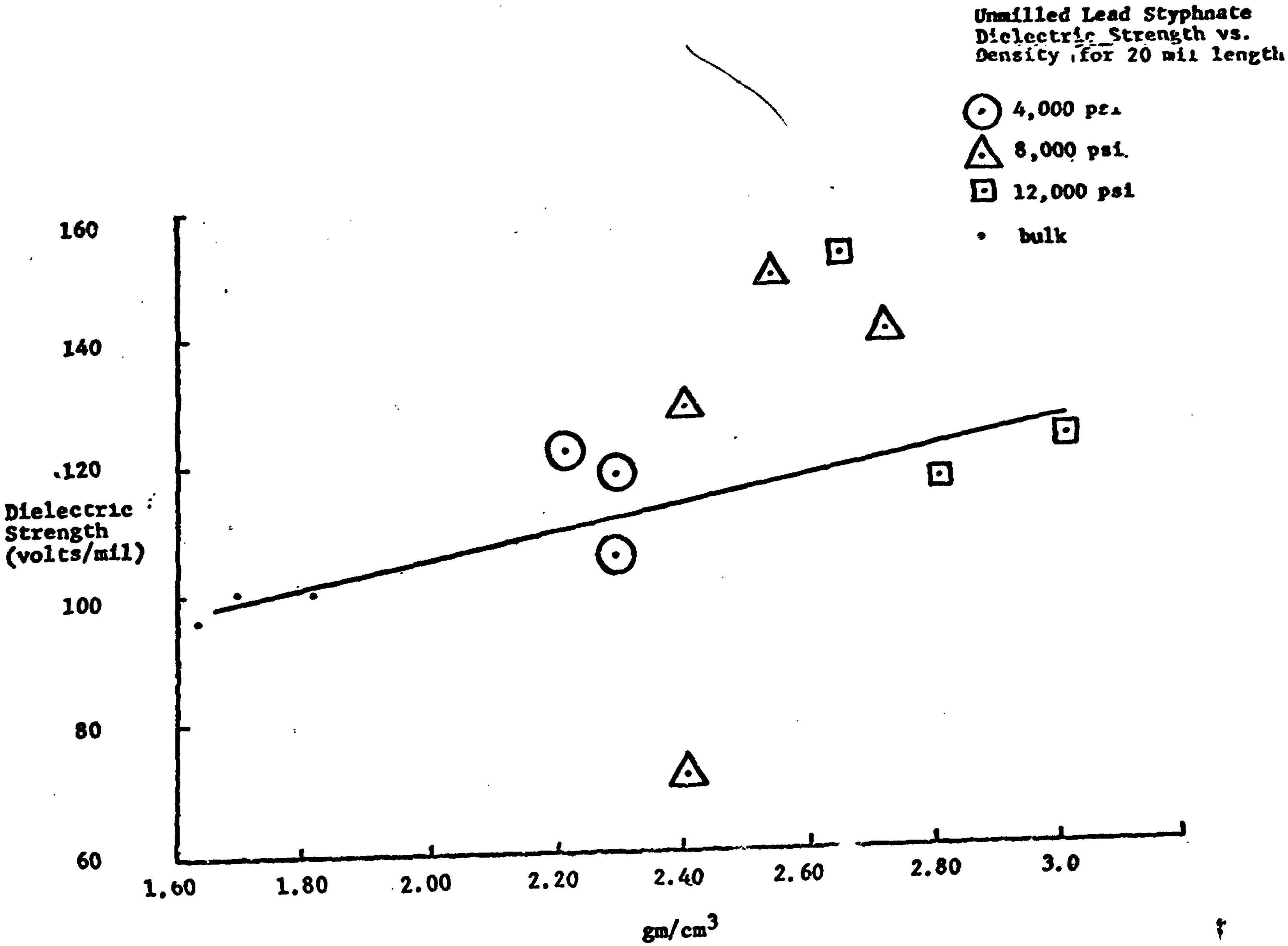

Dielectric Strength vs. Load Length for Unmilled Lead Styphnate at 8,000 psi
X = Average
= Points not included in Averages
175
150
125
100
75
50
Dielectric Strength (volts/mil)
0
10
20
30
40
50
length (mils)

FIGURE 9



Unmilled Lead Styphnate
Dielectric Strength vs.
Density for 20 mil length
4,000 psi
8,000 psi
12,000 psi
bulk
160
140
120
100
80
60
Dielectric
Strength
(volts/mil)
1.60
1.80
2.00
2.20
2.40
2.60
2.80
3.0
gm/cm³

FIGURE 10

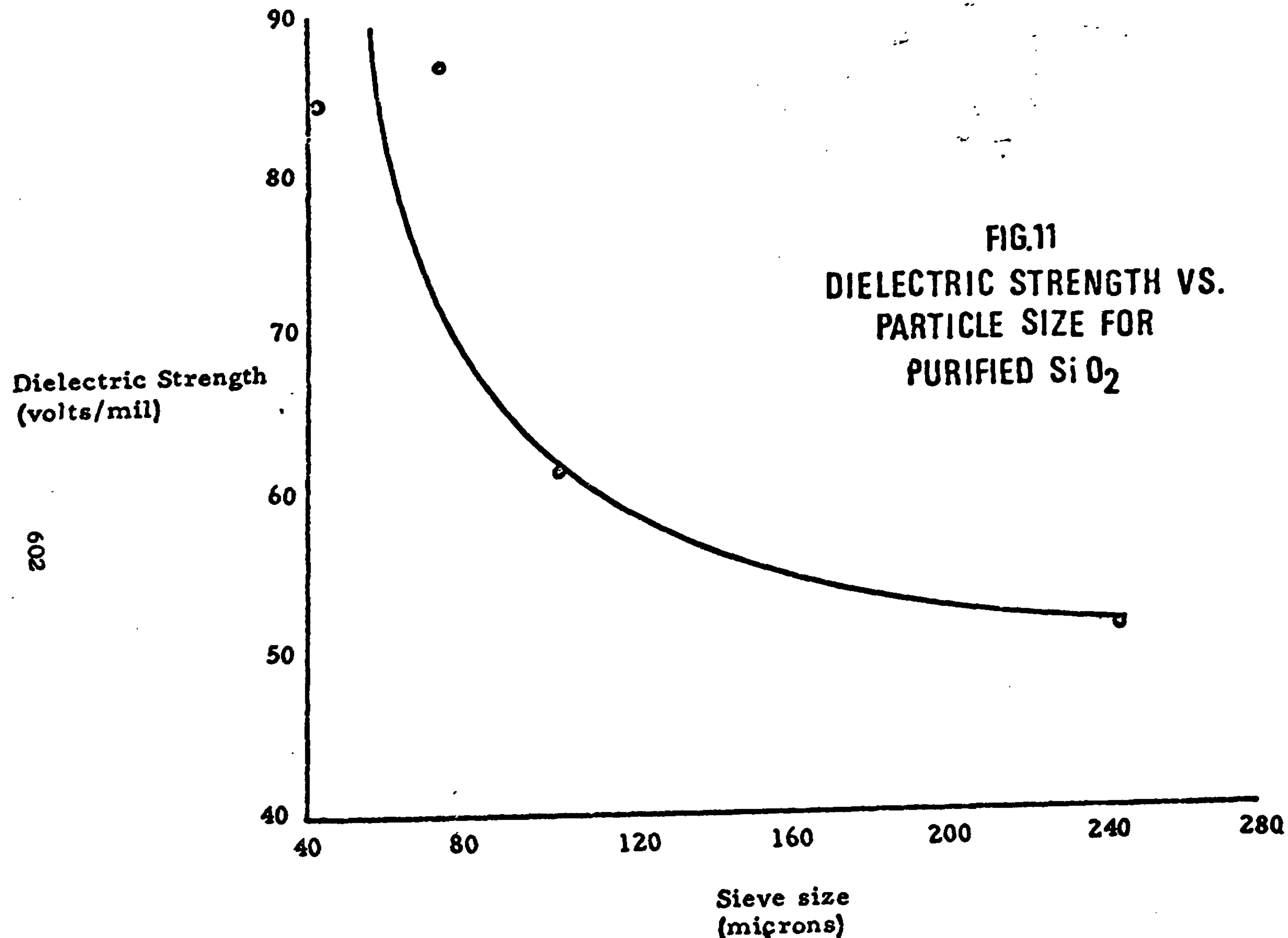
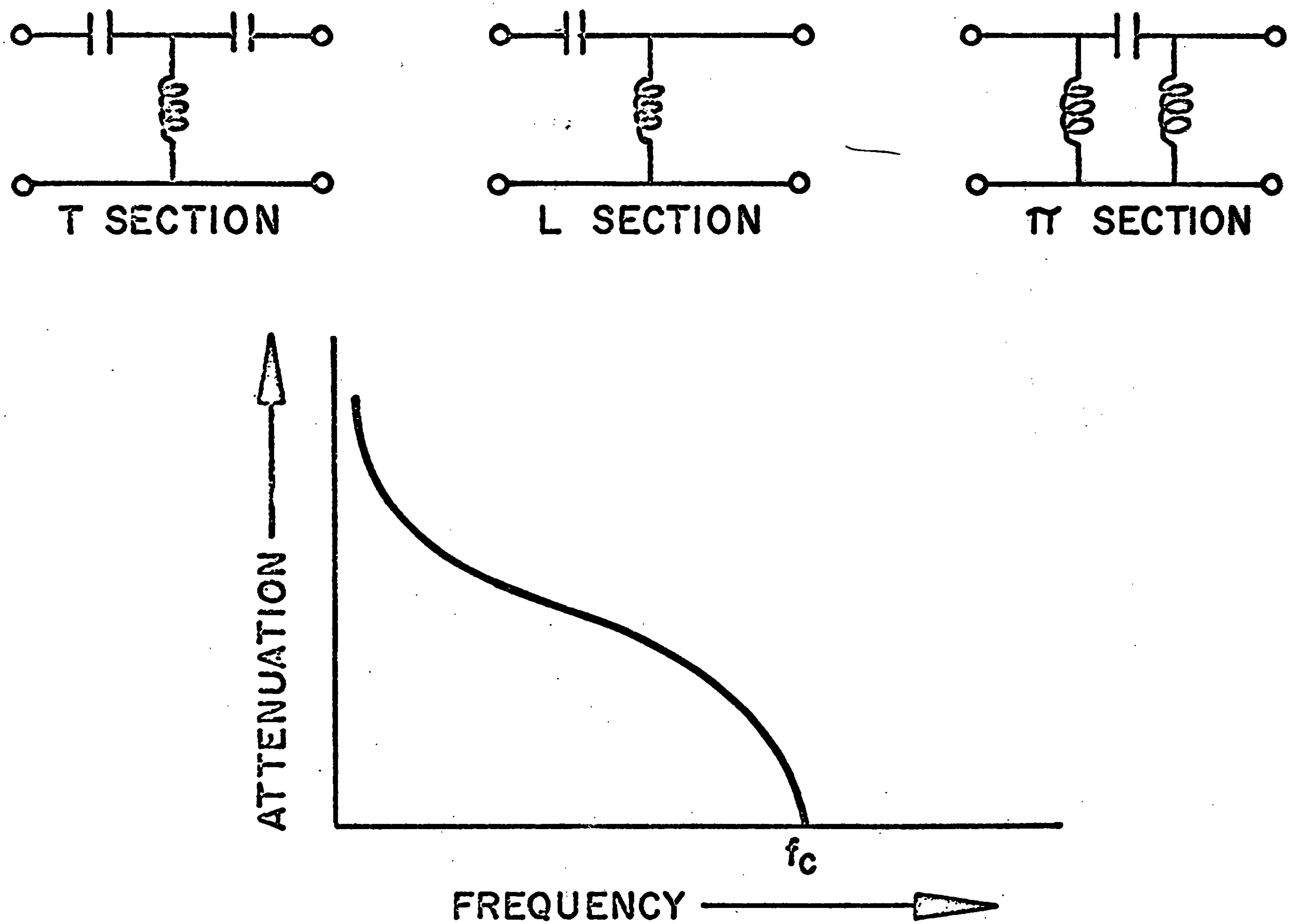
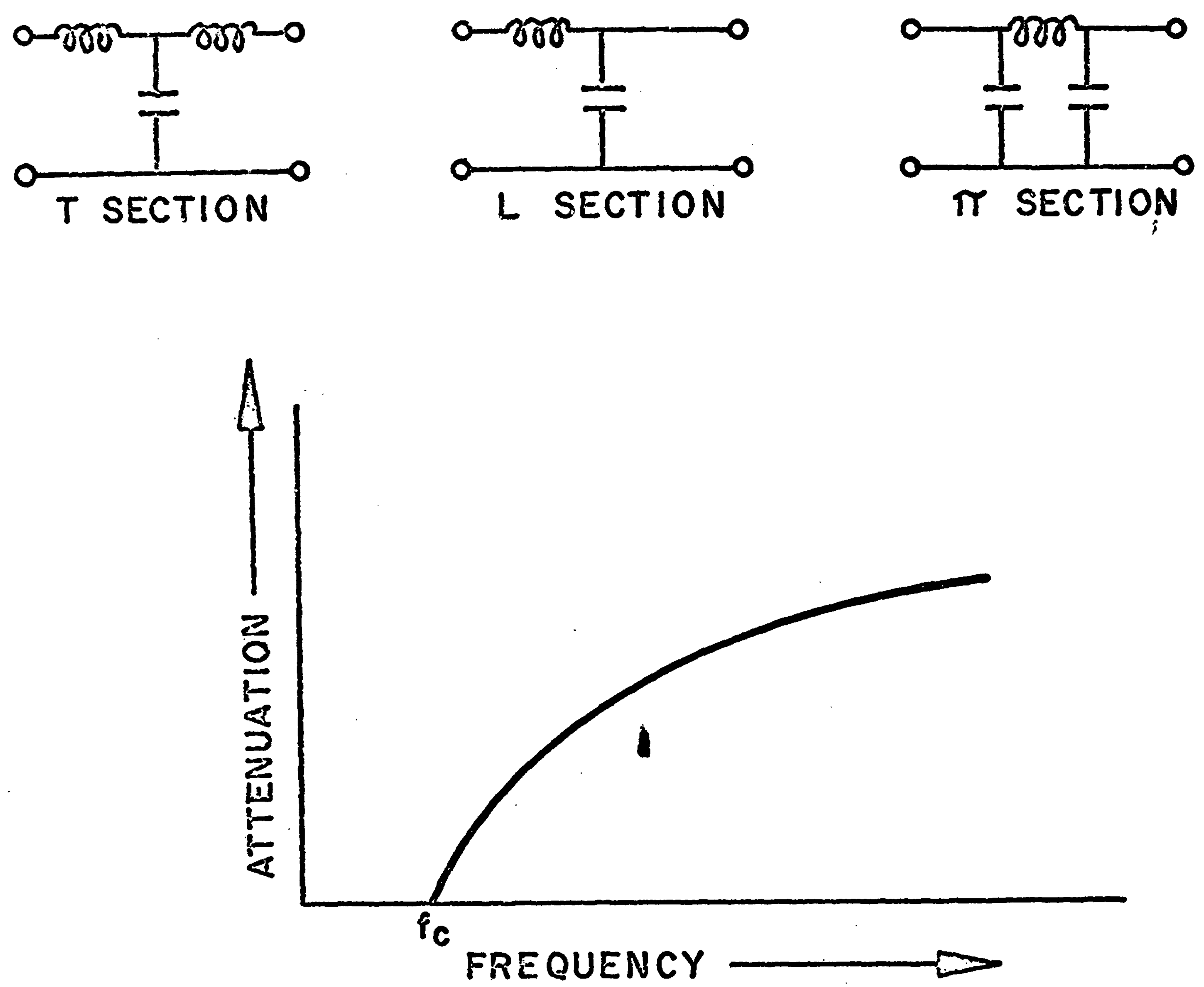
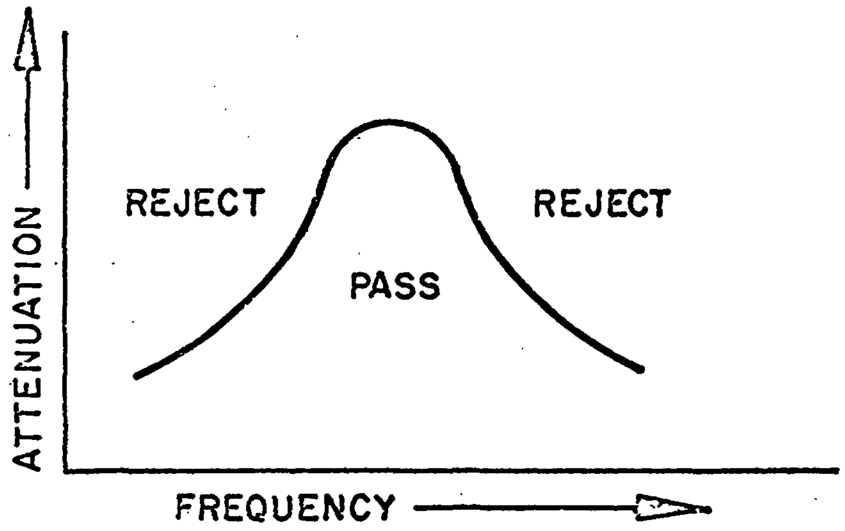


FIG.11
DIELECTRIC STRENGTH VS.
PARTICLE SIZE FOR
PURIFIED SiO_2

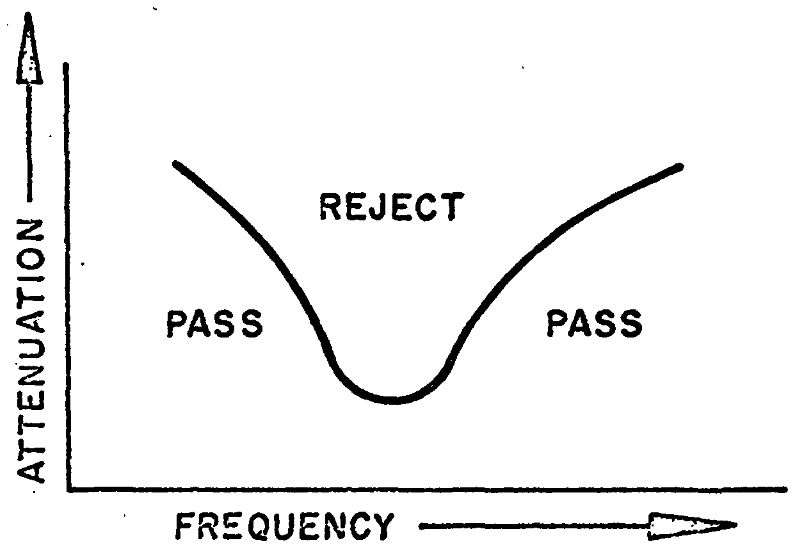
The eighth paper, "RF Protected EED's Utilizing Miniature RLC Networks" by Joseph E. Sidoti of Micro Precision Procuts, Inc., was not orally presented at the symposium but will be printed in the proceedings. This paper illustrates how various types of RLC circuits can be used as filters against radio frequency interference. In the sketches, performance characteristics are shown of various filter sections. In the last curve is shown the performance possible with ferrites and barium titanate materials as compared with the previously used carbonyl iron with iron phosphate coating.


T SECTION
L SECTION
π SECTION
ATTENUATION
f_c
FREQUENCY

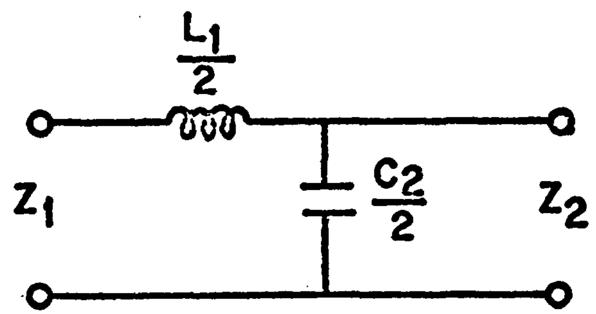

T SECTION
L SECTION
π SECTION
ATTENUATION
f_c
FREQUENCY



BAND-PASS CHARACTERISTIC CURVE



BAND-REJECT CHARACTERISTIC CURVE



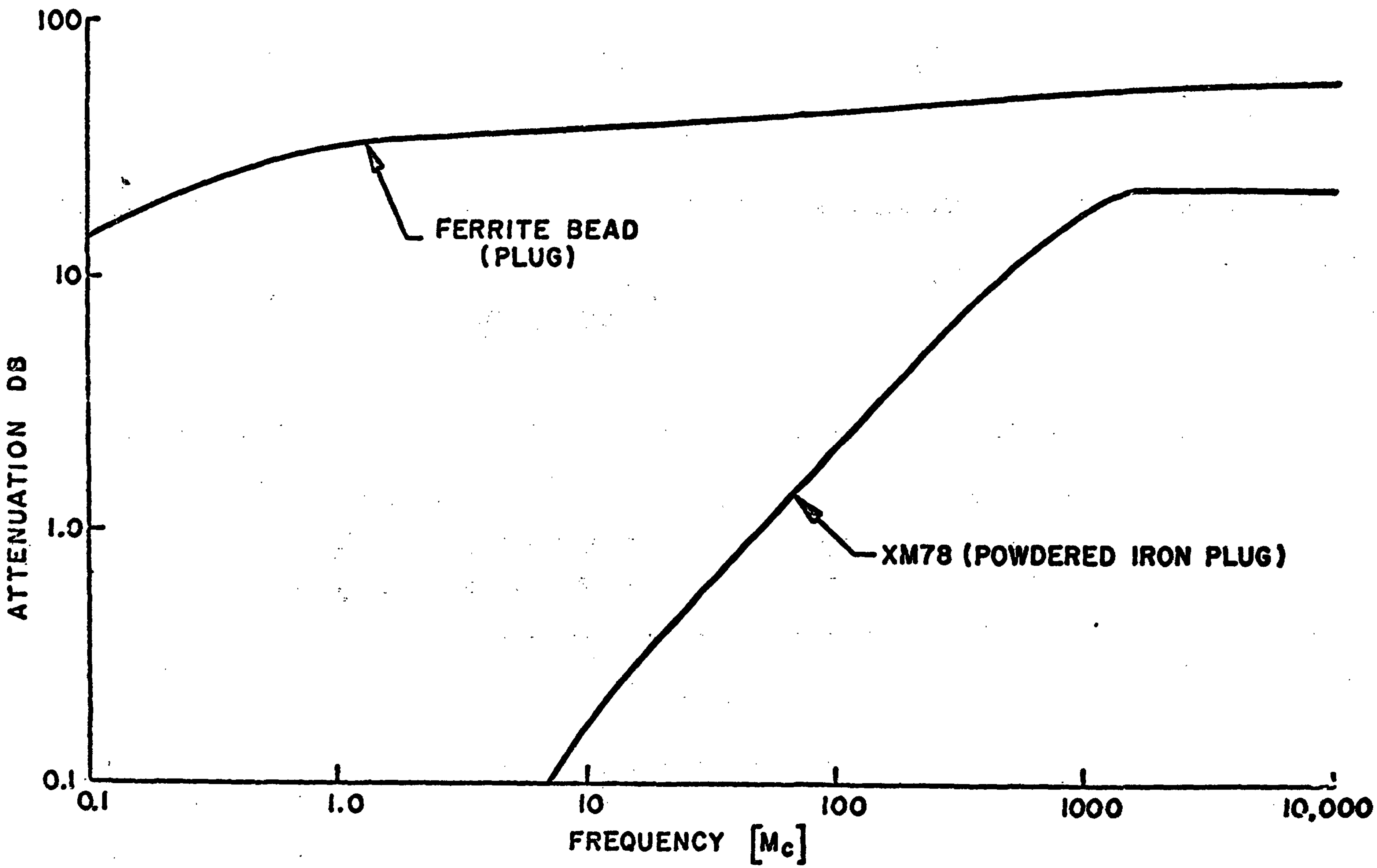
Z_1	=	INPUT IMPEDANCE	L_1	=	INDUCTANCE
Z_2	=	OUTPUT IMPEDANCE	C_2	=	CAPACITANCE
Z_0	=	CHARACTERISTIC IMPEDANCE	F_C	=	CUT-OFF FREQUENCY

THE CUT-OFF FREQUENCY IS SHOWN AS "fc", AND IT CAN BE COMPUTED FROM THE FOLLOWING RELATIONSHIPS:

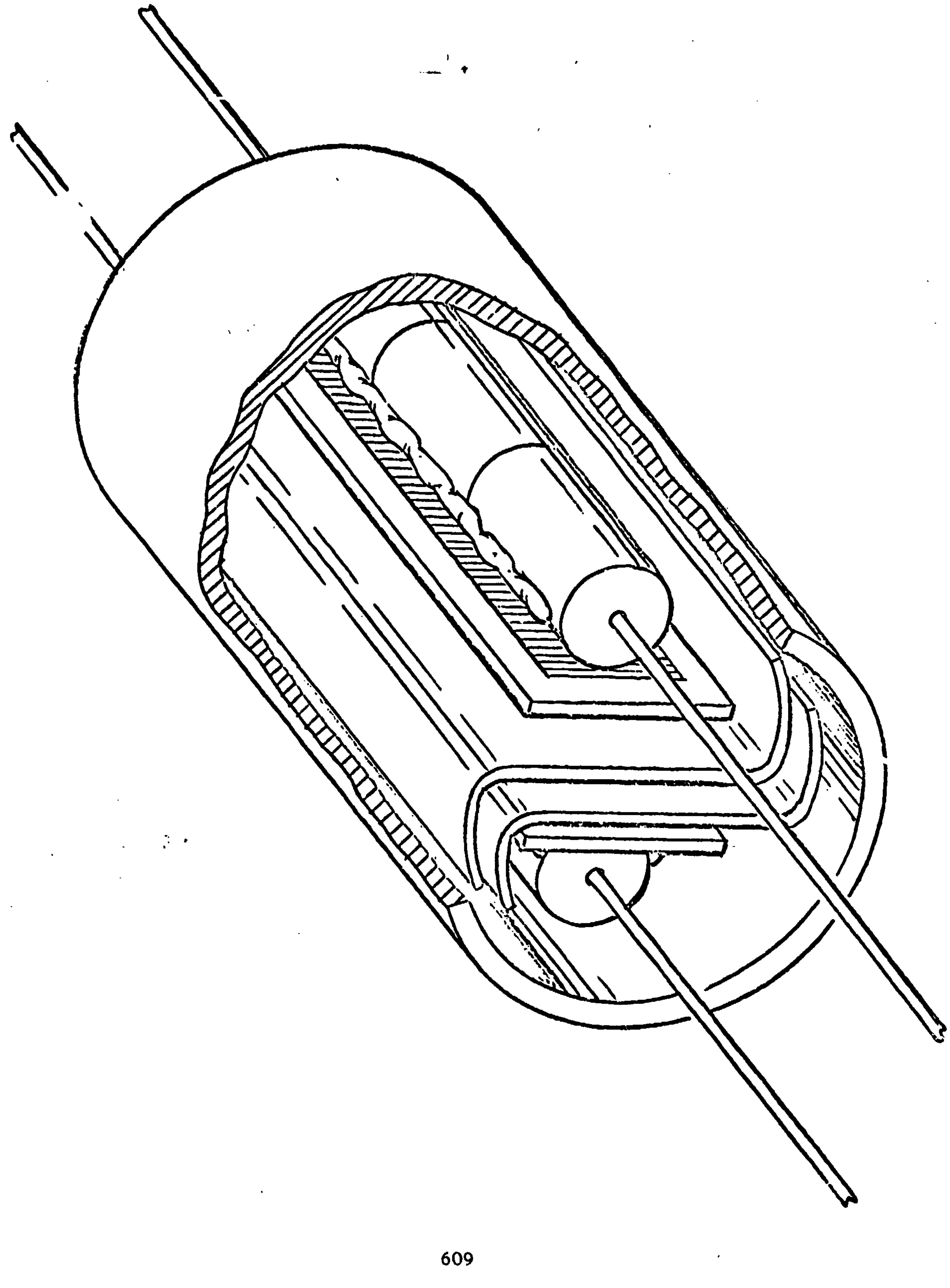
$$f_c = \frac{1}{\pi\sqrt{L_1 C_2}}$$

THE INTERRELATIONSHIPS OF THE REMAINING PARAMETERS CAN ALSO BE DESCRIBED BY THE FOLLOWING EQUATIONS:

$$L_1 = \frac{Z_0}{\pi f_c} \qquad C_2 = \frac{1}{2\pi \cdot f_c Z_0} \qquad Z = \sqrt{\frac{L_1}{C_2}}$$



ATTENUATION DB
100
10
1.0
0.1
0.1
1.0
10
100
1000
10,000
FREQUENCY [Mc]
FERRITE BEAD
(PLUG)
XM78 (POWDERED IRON PLUG)



Of the last three papers only the tenth was made available to me. This was by R. Streasau and R. Degner of the R. Stresau Laboratory, Inc., Spooner, Wisconsin, entitled, "Miniaturization of Out-of-Line Explosive Safety Systems." As your interest here is apparently only in the hazards problems and since this exhaustive paper is chiefly concerned with details of techniques for reducing the size of explosive components, I will not give you any detailed summary of it.

Let me just quote you the conclusion.

> "The miniaturization of fuze explosive trains offers substantial opportunities for improvement of ordnance. The greatest gains in this respect can be realized by the development of new design criteria, fabrication techniques, and evaluation procedures. Although it is to be anticipated that the effort to develop such criteria, techniques, and procedures will lead to invention, no such invention is necessary to realize very substantial benefits from miniaturization, since all essential concepts exist. The present need is for the detailed data whereby designs may be optimized, evaluation programs outlined, and production standards specified.
>
> "An electrically initiated explosive system that meets Navy standards of safety and reliability, has sufficient output to initiate standard booster explosives in current use, and has a total volume less than 1/2 cm^3 (or 1/32 $in.^3$) is entirely feasible. The data herein allow appreciably more latitude than would be needed for reasonable design and indicate the existence of several opportunities for improvement of performance not exploited in these experiments, which in turn suggests that further reduction in component dimensions is probably also feasible."

RECENT PROGRESS ON THE DEVELOPMENT OF INSENSITIVE EEDs

C. M. CORMACK
Naval Air Systems Command Headquarters

At the fifth EED Symposium, a number of papers were presented describing Research and Development work which is being done to provide electroexplosive devices (EEDs) which will be safer to use in the presence of high intensity electromagnetic radiation environments and electrostatic discharges than those currently in use. The basic approach here is to decrease sensitivity to electrical stimulus.

Several of these papers approached the problem by modification of the bridge geometry, fabrication techniques, and material content, for example:

(1) Menichelli at NOL/WO used the concept of maintaining a constant volume of bridge material on a standard initiator plug such as the one shown in Figure 1 but varied the surface area as shown in Figure 2.

Changing the surface area of the bridge element effects the heat loss factor (γ) in Rosenthal's simplified basic thermal equation

$$C_p \frac{d\theta}{dt} + \gamma\theta = P(t)$$

where C_p = Heat capacity of the bridge system (power-time/°temperature change)

γ = Heat loss factor (power/°temperature change)

θ = Temperature rise above ambient

$P(t)$ = Input power function

t = Time

As the surface area of the bridge element increases, γ will increase, and thus for a given C_p and θ (characteristics of the bridge element material and the explosive material being used), the input power function $P(t)$ will be increased.

Utilizing several different materials and adjusting the surface area by modifying the geometry, Menichelli was able to demonstrate the effect on the firing sensitivity of the bridge element. An example using cupron (a copper nickel alloy) is shown in Figure 3.

The 1 amp/1 watt for 5-minute no-fire criterion of several military specifications could be easily met by application of the above techniques.

Menichelli postulated that use of thinner films such as those obtained by vacuum deposition would be more effective in increasing the heat loss.

(2) Griffin from Pelmec Division of Quantic Industries described studies of a Microcircuit Bridge for High Reliability EEDs. He approached the problem of decreasing EED firing sensitivity by the use of Moly-Manganese Process (a technique developed in the vacuum tube industry for the production of ceramic to metal seals). This process results in a film approximately 1 mil thick primarily consisting of molybdenum metal sintered and intimately bonded to an alumina substrate and is referred to in the report as a microcircuit or MC bridge to differentiate it from a conventional wire bridge or a vacuum deposited film.

In the process, powdered molybdenum and manganese metals and/or their oxides are mixed in the form of a paint or ink which is applied to the ceramic part by brushing, spraying, or other techniques. It is then placed in a hydrogen atmosphere furnace and sintered at a temperature above 2000°F. The moly-manganese film is then plated for subsequent soldering or brazing to the metal part. The film is predominatly molybdenum since most of the manganese and other oxides tend to form a glassy interface between the metal film and the ceramic substrate. Molybdenum is a refractory material having a very high melting point (4700°F). However, it is also a reactive metal and is readily oxidized. At low temperatures the metal is protected by an oxide film (MoO_3). At about 1400°F, the oxide becomes volatile so that surface protection is lost, and rapid oxidation can occur. This is demonstrated in Figure 4 for widely different heating rates.

When an explosive (normal lead styphnate) was bonded to the moly-manganese bridge with nitro-cellulose lacquer and different heating rates applied, the temperature and time of initiation of the explosive was determined by means of a sudden spike on the voltage and current traces. This effect was caused by the heat flash produced by the explosion which instantaneously heated the bridge about 50 degrees, resulting in an increase in resistance and a compounding shift in the voltage and current across the bridge (see Figure 5).

Figure 6 shows the various configurations that have actually been built and tested. Item A had a nominal resistance of 1 ohm and a no-fire level of 2 amps and 4 watts, together with a functioning time of 1 millisecond at 4-5 amps. Item B had a nominal resistance of 1/2 ohm and gave 2 watts of power dissipation at 2 amps. Item C had an 0.07 ohm resistance with a no-fire capability in excess of 5 amps and 1.5 watts.

Using the above technique a 5 amp/1.5 watt/5 minute no-fire initiator has been fabricated. A metal oxidant charge was used in place of the lead styphnate and the characteristics determined are shown in Figure 7.

The Pelmac Model 1353 initiator consists of an all ceramic initiator that is heat sterilizable and is insensitive to 25 kV discharge from a 500 picofarad capacitor in all modes. The unit meets the 1 amp/1 watt/5 minute no-fire requirements with a 0.4 or 1.0 ohm bridge resistance and can be used for pyrotechnic or high explosive initiation.

Griffin recommended establishment of a constant power no-fire test in addition to the constant current test.

(3) Stresau and Peterson of Stresau Labs, and Corren and Coler of Markite Engineering Co. collaborated in a study and development of conductive plastics as bridge elements for EEDs. Units meeting the 1 amp/1 watt/5 minute no-fire criterion have been fabricated.

Conductive plastics have also been used to fabricate extremely sensitive initiators (100 ergs at 5 volts) and of tiny size as shown in Figure 8.

In addition to the "high power" requirements (1 watt) a relatively "low energy" requirement (10,000 ergs) was established for an NOL/Corona application. This combination was deemed feasible since the "high power" requires that the heat loss factor of the bridge element be large while the "low energy" requires that its heat capacity be low. Small heat capacity ordinarily calls for small bridge element volume. This leads to the use of microscopically fine wires. It was found however that the relationship of heat capacity and firing energy is substantially altered when conductive plastic bridges are used. When certain critical currents are exceeded, local high temperatures are generated which are far in excess of what would be expected from the total volume of the bridge material.

The items fabricated for the NOL/Corona requirement were designed to meet the requirements of MIL I 23659 (WEP) and MIL STD 322. They were tested with results as shown in Figure 9. It is evident that none of the environmental exposures resulted in deterioration of the 1 amp/1 watt/5 minute criterion.

Figure 10 shows the effect of environmental exposure on pulse sensitivity and while the sample size is limited, indications are that all units functioned below the 10,000 erg requirement.

Figure 11 shows an apparent rise in the mean energy to fire for all but the 160°F test.

The Markite conductive plastic appears to behave in an intrinsically different manner from that of the more conventional types of bridge materials. Figure 12 is an example, and shows curves generated on the oscilloscope when the current is increased from 0 to the point at which the plastic explodes. The resistance wire on the other hand maintains a simple ohmic relationship. Current inputs up to point "A" on Figure 12 do not cause irreversible changes in the material.

Other papers discussed Research and Development efforts to reduce EED sensitivity by the use of different explosives and/or mixtures of explosives, for example:

(1) Austing and Kennedy of IIT Research Institute and Chamberlain and Stresau of Stresau Labs. investigated the use of metal-metal oxide mixtures in contact with electrically pulsed bridge wires. The systems that were studied included aluminum-tungsten oxide, aluminum-copper oxide, aluminum-vanadium pentoxide, and aluminum-molybdic oxide. These mixtures are highly exothermic, with reaction temperatures in excess of 2500°K. Metal-metal oxides therefore serve as good ignition sources for a variety of explosive type components. Representative data were shown which indicated that EEDs incorporating the proper metal-metal oxide system (1) are capable of withstanding static electric discharge pulses in excess of those generated by the human body and (2) can be designed to provide a 5 amp/5 watt no-fire capability.

The above studies, and others mentioned at this meeting, have been undertaken primarily because of the growing awareness of the potential effects of RF environments, which may be present at the time and place where weapons are handled, loaded, and/or launched on the EEDs within these weapons. The attempt to solve this problem by desensitizing the EEDs represents but one approach and is based on the assumption that no more than 1 ampere or 1 watt will be delivered to the EED by spurious sources.

To understand the full scope of the RF hazards problem and other approaches to its solution, let us first examine the RF environment as it has been defined by various sources, then let us see how the energy from these fields may be induced into EEDs and what the "worst case" may be, and finally, examine a few of the techniques by which the RF hazards can be minimized or eliminated.

The U. S. Navy's maximum RF environment has been determined from numerous measurements aboard ship and has been published as shown in Figure 13. While these values have not been adopted by the U. S. Army or U. S. Air Force, the following environment was specified for one air-launched weapon tested by the Navy for the Air Force:

19.3 V/m for communications-type transmissions

60 MW/cm^2 for radar-type emissions.

The United Kingdom has specified the environment shown in Figure 14 for the Royal Navy. It should be noted that their environment differs from ours in the 1.5-32 mc/s (where theirs is double ours); in the radar "S" band, 2300-3700 mc/s (where theirs is five times ours), and in the radar "X" band, 7900-10,000 mc/s (where theirs is 20% higher than ours).

The available power in a given RF environment is primarily a function of the source power, the source antenna gain, and the location of the weapon relative to the source. The relationship of the primary factors that establish the RF environmental power is:

$$P_A = \frac{G_T W_T}{4\pi r^2}$$

where P_A = Power per unit area (watts/sq meter)

G_T = Gain of the transmitting antenna

W_T = Power of the transmitter (watts)

r = Distance from the source to the point of observation (meters).

In the far field, there is a direct relationship between P_A and E (the electric field strength)

$$E = 19.3 P_A$$

where E = Electric field strength in V/m

P_A = Power per unit area in watts/sq meter.

The basic radiation characteristics of antenna systems are usually referenced to an isotropic radiation source. An isotropic radiator is a theoretical concept, defined as a point source of radiated energy with radiation properties that are identical in all radial directions. For an isotropic radiator in free space, 100% efficient and radiating a total average power W_T in all directions, the power density P_A on the surface of a sphere of radius r, concentric with the point source will be simply the total radiated power divided by the surface of the sphere which is proportional to the radius squared. Therefore, power density in free space decreases as an inverse function of the distance squared from the radiating source.

If the power source is not an isotropic radiator and therefore radiates with a gain of G_T in a given direction, then the power density at the distance r in the far field region in that direction is:

$$P_A = \frac{G_T W_T}{4\pi r^2} .$$

The power received by an antenna (in our case a weapon system) in a uniform field is a function of its effective aperture and the power density at the antenna location, that is:

$$W_R = A_{er} P_A$$

where W_R = the power delivered the load impedance across the antenna terminals in milliwa ,s

A_{er} = the effective area of the receiving antenna in square meters

P_A = power density in watts/square meter

The equation for the effective area of a receiving antenna as stated below is the maximum effective area of an antenna. This condition only occurs when an antenna is matched to its load:

$$A_{er} = \frac{G_R \lambda^2}{4\pi}$$

where G_R = gain of the receiving antenna; it does not include effects of impedance mismatch between antenna and load

λ = wavelength.

Substituting A_{er} in the expression for W_R given above, yields

$$W_R = \frac{P_A G_R \lambda^2}{4\pi} \text{ (watts)} .$$

The following sample calculation illustrates the principle for calculating the induced current in an EED bridge wire assuming that the EED terminates a half wave resonant dipole antenna as shown in Figure 15. The following conditions are assumed:

(1) The lead wire lengths (AB and CD) are arranged so that a resonant 1/2 wave dipole is formed. This antenna is terminated in a 1 ohm EED.

(2) The characteristic impedance and length of the transmission line (formed by BE and CF) are such that the 1 ohm load is matched to the antenna. The losses of the transmission line are neglected.

(3) The antenna gain (G_R) relative to an isotropic antenna is taken as 1.64.

(4) The field strength is assumed to be 100 V/m at 75 Mc (λ = 4 meters).

Utilizing the formula above:

$$W_R = \frac{P_A \, G_R \, \lambda^2}{4\pi}$$

we have:

$$W_R = \frac{(26.5)\ (1.64)}{4\ (3.14)}\ (16) = 55.3 \text{ watts}$$

The current I in the bridge wire EED is established from:

$$W = I^2 R$$

where W = power in watts

I = current in amperes

R = resistance in ohms.

If R is taken as one ohm:

$$I = (W/R)^{1/2} \quad \text{or} \quad (55.3)^{1/2} = 7.5 \text{ amperes}$$

This sample calculation was chosen because, in all of the HERO tests, the induced current in an EED was never found to exceed the value calculated as above on the assumption that the receiving antenna was a resonate half-wave dipole.

The example given above may be used to depict the worst case situation where all protection normally found in a weapon system--such as shielded cables and shielded enclosures--has been omitted.

The structural enclosure of a weapons system provides some RF shielding for the enclosed EEDs. In actual conditions found in weapons systems, the problem of analyzing the details of the complete mechanism of the transfer of RF energy from the environment to an EED does not lend itself to a straightforward theoretical solution. However, it is clearly unlikely that the worst-case example should occur in a completed weapons system.

The exterior of the weapon may be energized either by incident fields from external sources or by direct coupling from its own internal sources. Whatever the course, the surface distribution of current and charge may exhibit stationary patterns depending on the method of excitation, the wavelength of the excitation current, and the geometry of the weapon. These patterns are in general very complicated.

In electrical and mechanical form, the receiving antennas that contribute to the RF Hazards problem in actual weapons systems are not necessarily recognizable as antennas. They may take the forms of umbilical cables, access doors and hatches, or discontinuities in weapon skins and shields, but they nevertheless function as linear antennas, current loops, or cavity and slot aperture antennas.

Some of the ways in which umbilical cables, apertures, and discontinuities in the weapon skin can function as receiving antennas for RF energy are shown in Figure 16. Panel (a) of the figure illustrates an umbilical cable as the receiving antenna (vertical or loop) and an internal loop antenna consisting of an EED and its associated wiring. External cables can act as effective receiving antennas when exposed to RF energy, permitting the transfer of RF currents into the weapon; and direct or inductive coupling to an EED bridge wire can result. This type of receiving antenna can be an effective receiver at communications frequencies, depending on the length of the external cables and their connections.

Panels (b) and (c) of the figure illustrate apertures in a weapon skin acting as receiving antennas. These apertures are effective receiving antennas at frequencies at which their dimensions approach one wavelength. The amount of RF energy transferred into the cavity becomes more pronounced when the dimensions of the cavity approach one wavelength. This occurs most often at radar frequencies. The RF energy is coupled from the fields developed in the cavity to the bridge wire by capacitive and inductive means.

Panel (d) illustrates energy transfer occurring as a result of an RF arc. When connection is either made or broken between any two weapon elements having different RF potentials (e.g., connectors between weapon and launcher or between weapon and test equipment), arcs occur which can produce large amounts of energy in the DC and audio frequency ranges. If RF arcs occur in the firing circuits and there is a complete DC circuit, this energy can be delivered to an EED even if the EED is protected by a low-pass filter. Studies are being made to determine the extent of the problem in weapons, to identify the present design practices that are effective in minimizing the problem, and to develop new means of preventing the arcing problem. Some progress has been made in the suppression of the arcing hazard.

Under any of the conditions illustrated in Figure 16, the energy transfer can be increased by personnel in proximity to the weapon. The human body displays receiving antenna characteristics, and the addition of personnel can increase the efficiency of the transfer path of RF energy to the susceptible portions of the weapon.

Attempts to analyze the amount of energy coupling by a theoretical study of apertures, lead-to-lead intercoupling, lengths of wires, impedance match or mismatch, and effectiveness of shielding have all failed, due to the complexity of the problem.

There are three basic approaches to the solution of the HERO problem which do not impose any restrictions on the designers of EEDs or power supplies:

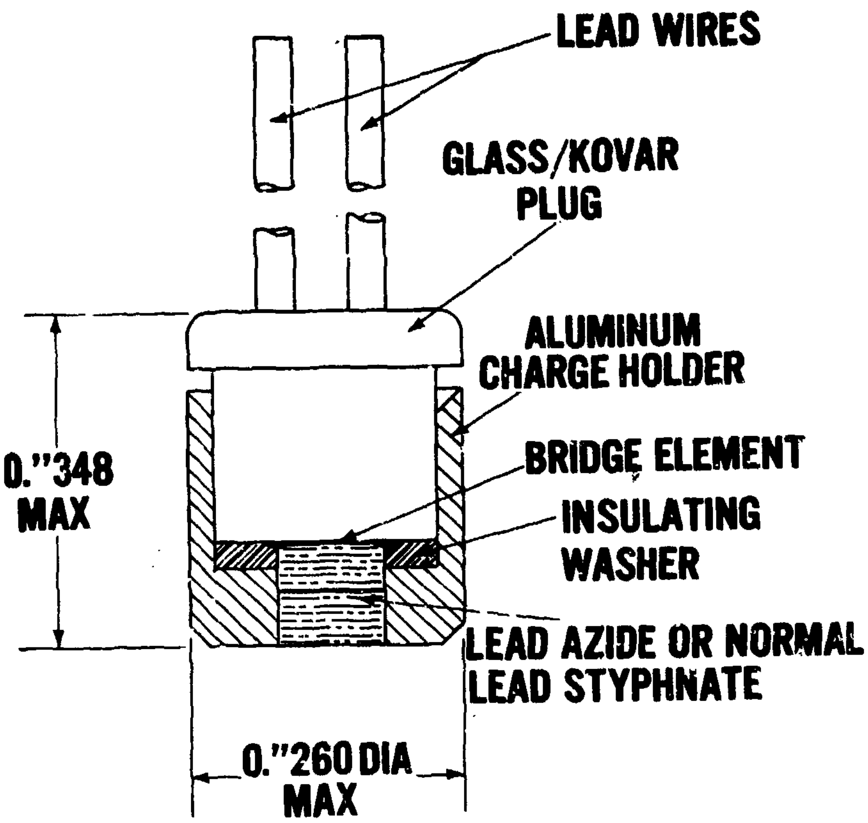
(1) The Conductive Box Concept as shown in Figure 17. This approach consists of enclosing all EEDs and their associated firing circuits (including all power sources, transmission lines, and switching and arming devices) within a completely closed conductive shield or box. Incident electromagnetic energy on a conductive surface is attenuated exponentially with respect to the depth of penetration. Most weapons utilize a metallic skin; and ordinarily, the skin thickness required for structural purposes far exceeds the thickness required to provide an effective shield. Therefore, the conductive box can be an effective means of solving the RF Hazards problem. If the entire weapons system can be enclosed in such a box, the only precaution to be observed is the proper design of the metallic joints.

(2) Compartmentalization and shielding of Compartments and Connections as shown in Figure 18. In many cases, economic or weight limitations on the physical structure of the weapons system do not permit direct application of the Conductive Box Concept. Yet it can be extended to fit this situation, because the various components of the weapon can be compartmentalized and shielded, and then interconnected via shielded circuits. Note that the circuit shield must be connected to the compartment or component shield along the entire periphery of the shield.

(3) The Use of RF Filters or Suppression Devices as shown in Figure 19. Many weapons require electrical stimuli of one or several forms to perform the launch function, and it is impossible or impractical to keep all conductors within one continuous shield. Therefore, RF energy must be excluded by some other method. A logical choice is an RF discriminator, e.g., a low-pass electric wave filter.

The design or selection of a proper filter or RF suppression device is important because all external wiring acts effectively as a receiving antenna and conducts the received energy to the EED.

The application of the above design principles is shown in the following slides. Figure 20, Holes and Access Parts in Weapon Sections; Figure 21, Unequal Lead Lengths and Twisted Shielded Pair; Figure 22, Weapon Launcher Interface and Umbilical Mating; Figure 23, Shield Termination For Electrical Connectors.



INITIATOR ASSEMBLY

Figure 1

TABLE 1
RESULTS OF SENSITIVITY TESTING

BRIDGE ELEMENT CONFIGURATION	DIMENSIONS (MILS)	CROSS SECTIONAL AREAS (SQUARE MILS)	PERIMETER (MILS)	MEAN VALUES: CAPACITOR DISCHARGE (ERGS) [1]	MEAN VALUES: PULSED CONSTANT CURRENT [2] TIME (MILLISEC)	MEAN VALUES: PULSED CONSTANT CURRENT [2] ENERGY (ERGS)	MEAN VALUES: CONTINUOUS CONSTANT CURRENT (AMP^2) [3]
	3.5 DIA	9.6	11	378,000	12.9	419,000	7.7
	1 × 10	10	22	343,000	22.5	732,000	8.1
	0.5 × 20	10	41	403,000	30.4	988,000	9.4

1. VARIABLE VOLTAGE; 100 MICROFARADS
2. VARIABLE TIME; 5-AMPERE PULSE
3. VARIABLE CURRENT; 10 SECONDS APPLICATION

SAMPLE SIZE ≅ 50

BRIDGE ELEMENT MATERIAL = CUPRON (COPPER, NICKLE ALLOY, 55/45)
EXPLOSIVE MATERIAL ON THE BRIDGE ELEMENT = LEAD AZIDE

Figure 2

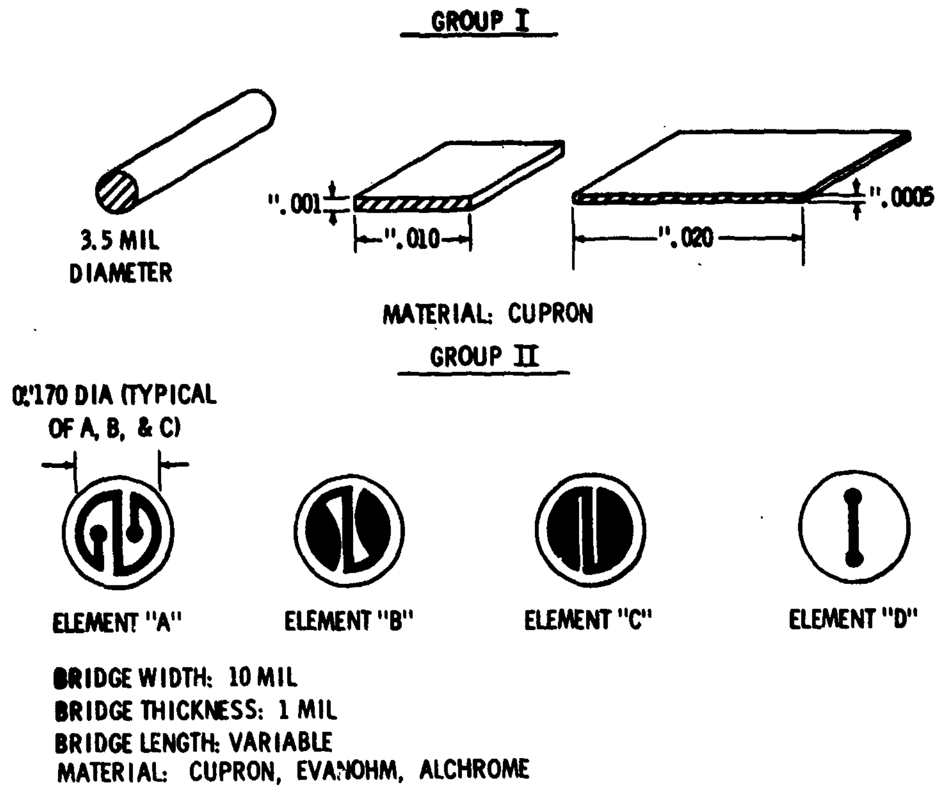


FIG. 3 BRIDGE ELEMENT DESIGNS

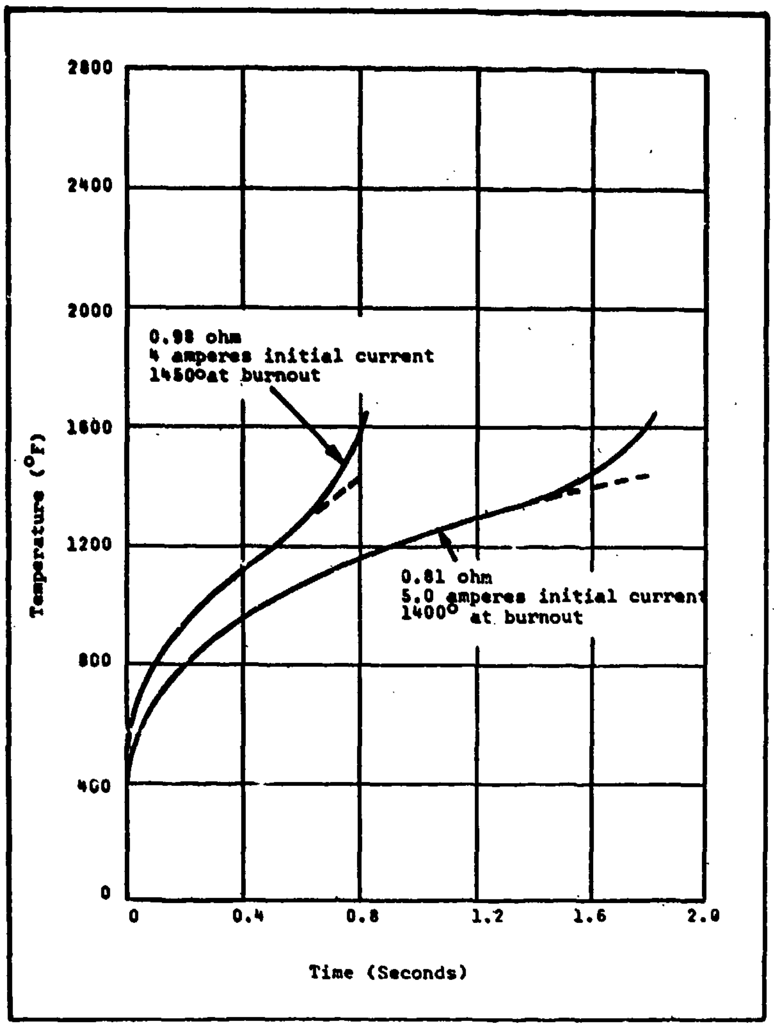


FIGURE 4 - Temperature versus Time for Selected Moly-Manganese Film Bridges.

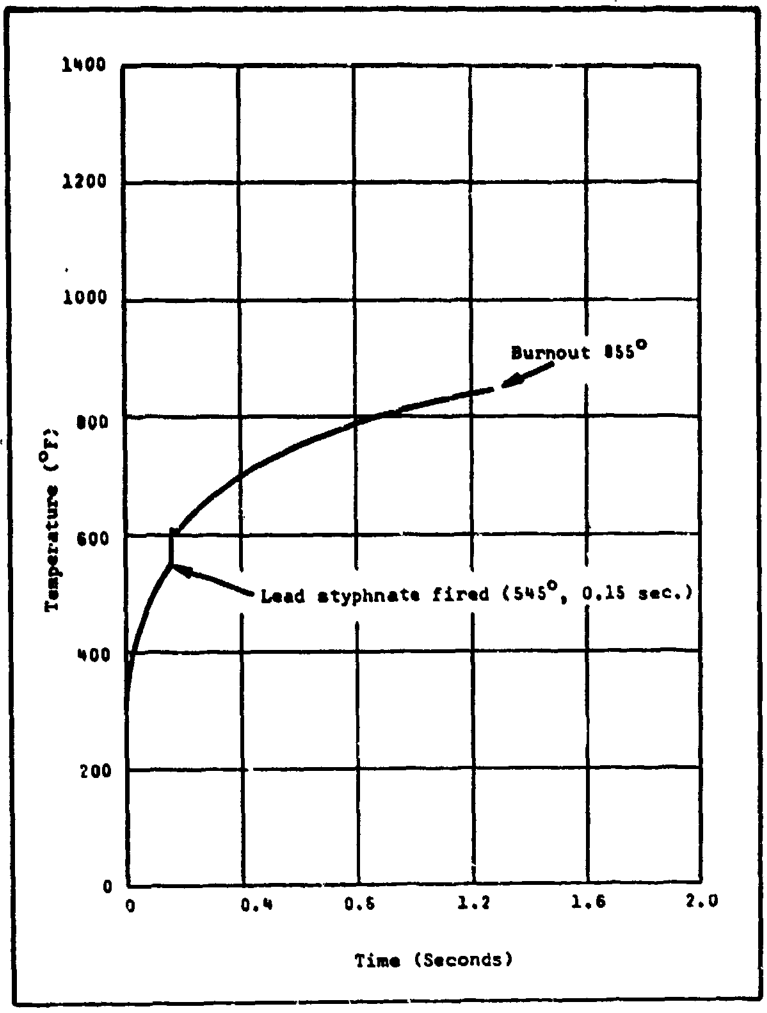


FIGURE 5 - Temperature versus Time for a 1.7-ohm Moly-Manganese Film Bridge with Lead Styphnate Charge Subjected to a 3-ampere Firing Current.

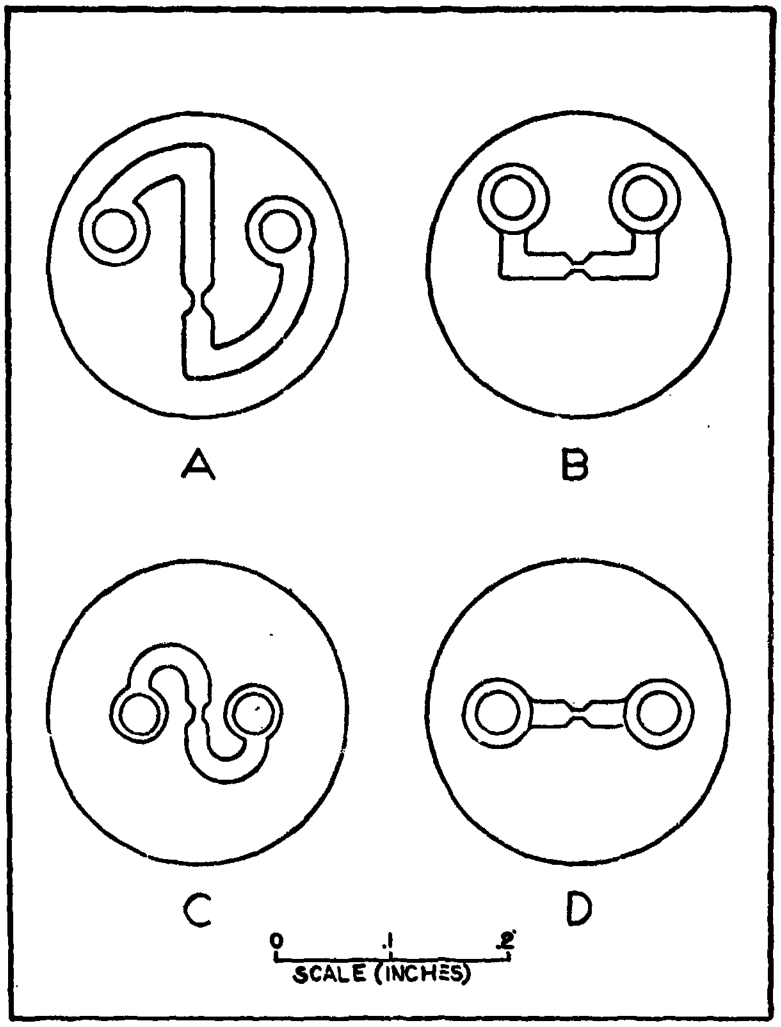


Figure 6

TEST	MEASURED PERFORMANCE
Bridge Circuit Resistance:	.07 ohms
DC Dielectric Breakdown (Pin/Case):	>2,500 volts
AC Dielectric Breakdown (Pin/Case):	>1,500 RMS volts, 60 ~
Electrostatic Discharge (Pin/Pin & Pin/Case):	25 kv, DC, 500 MMFD
No-Fire Sensitivity:	>5 ampere/1.5 watt/5-minute
Function Time (15 Ampere Firing Current):	.007 seconds
Post-Firing Resistance (Pin/Pin & Pin/Case):	> 5000 ohms

FIGURE 7 - Summary of Measured Performance Capabilities, Pelmec 5-Ampere/1.5 Watt MCB Initiator

Figure 7

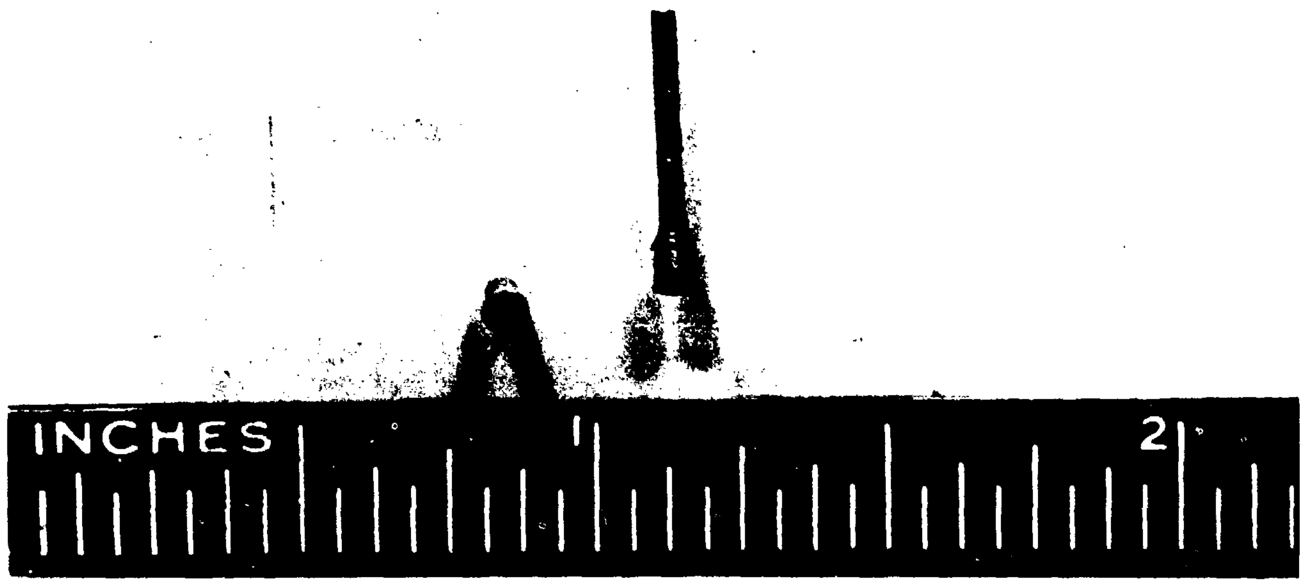


Figure 8

/0

CURRENT POWER SENSITIVITY

EXPOSURE BEFORE TEST	AS LOADED	JAN. TEMP. HUMD. CYCLE	HIGH TEMP. STORAGE	CONDITIONED & TESTED AT 160°F	-65°F	FORTY FOOT DROP TEST	VIBRATION TEST	JOLT TEST
NO. OF DETONATORS	25	20	12	10	10			
AMPS MEAN	1.78	1.71	1.89	1.88	1.79	0/5@1.0	0/4@1.0	0/3@1.0
DENT SIZE AVERAGE INCHES	0.017	0.013	0.018	0.017	0.012			
WATTS MEAN	2.22	2.43	3.80	1.87	1.27	0/5@1.0	0/4@1.0	0/3@1.0

Figure 9

PULSE SENSITIVITY AS LOADED

EXPOSURE BEFORE TEST	AS LOADED	JAN. TEMP. HUMD. CYCLE	HIGH TEMP. STORAGE	CONDITIONED & TESTED AT 160°F	AT -65°F
NO. OF DETONATORS	29	20	11	10	9
ERGS MEAN	4630	4200	7140	4220	7650
FUNCT. TIME MICRO SECS. AVERAGE	27	51	49	26	34
DENT SIZE AVERAGE INCHES	0.014	0.014	0.017	0.018	0.015

Figure 10

PULSE SENSISTIVITY AFTER ONE WATT - ONE AMP.

EXPOSURE BEFORE TEST	AS LOADED	JAN. TEMP. HUMD. CYCLE	HIGH TEMP. STORAGE	CONDITIONED & TESTED AT 160°F	-65°F	FORTY FOOT DROP TEST	VIBRA-TION TEST	JOLT TEST
NO. OF DETONATORS	25	17	12	10	10	5	4	3
ERGS MEAN	5670	8850	8410	6000	7130	5/5a 10,000	4/4a 10,000	0/3a 10,00C
FUNCTIONING TIME MICRO SEC. AVER.	26	50	46	20	64	23	23	
DENT SIZE AVERAGE INCHES	0.016	0.016	0.017	0.016	0.014	0.020	0.017	

Figure 11

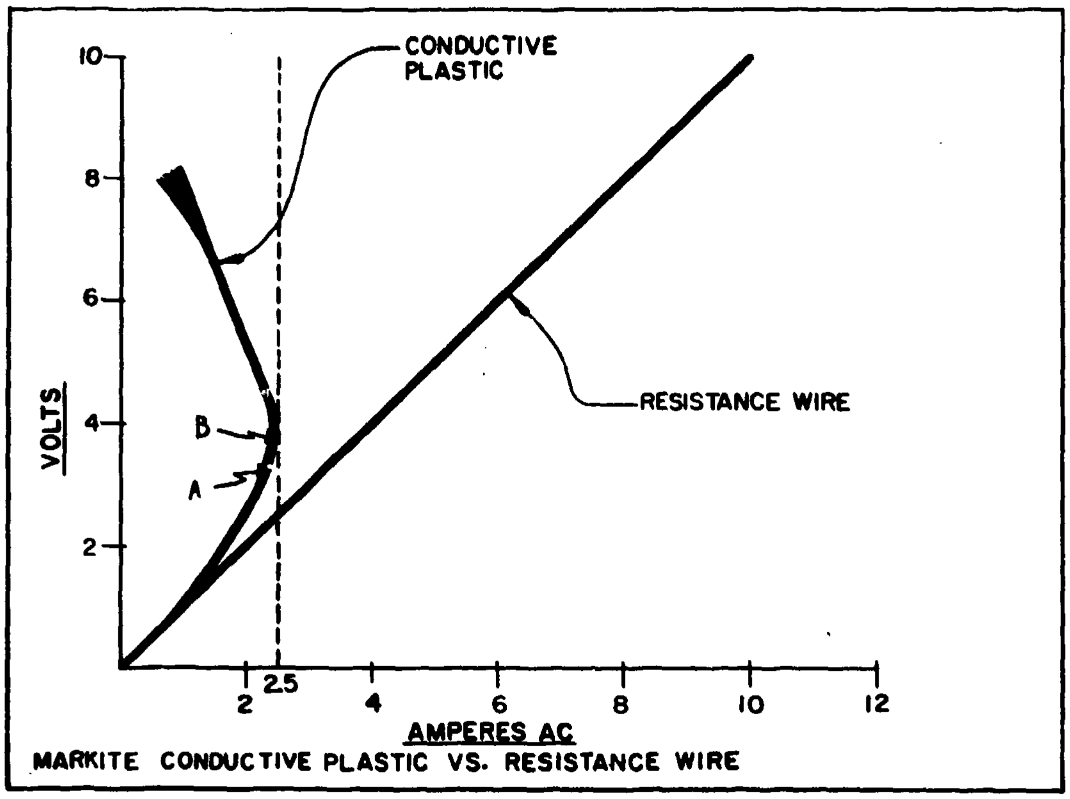

CONDUCTIVE PLASTIC
RESISTANCE WIRE
VOLTS
10
8
6
4
2
B
A
2
2.5
4
6
8
10
12
AMPERES AC
MARKITE CONDUCTIVE PLASTIC VS. RESISTANCE WIRE

Figure 12

MAXIMUM ENVIRONMENTAL LEVELS (UNPERTURBED FIELD) FOR USE IN WEAPON DESIGN

(a) Generated by Communications Systems (Continuous Wave, Unmodulated Carrier Values)

f Frequency (Mc)	E Electric Field (volts/meter)	H Magnetic Field (ampere turns per meter)	P_A Field Intensity (average power density in milliwatts per sq. centimeter)
.25 - .535	300	.5	
2 - 32	100	.5	
100 - 156			.01
225 - 400			.01

(b) Generated by Radar Syst ns

f Frequency (Mc)	P_A Field Intensity (average power density in milliwatts per sq. centimeter)
200 - 225	10
400 - 450	1
1000 - 1300	1
2700 - 3600	10
5400 - 5900	100
8500 - 10300	100

Figure 13

ROYAL NAVY RF ENVIRONMENT

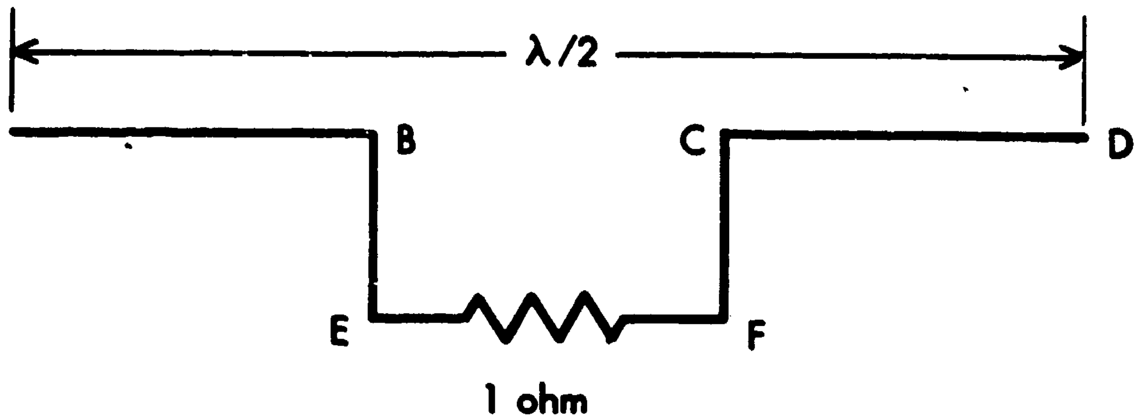
(a) Communications Systems

f Frequency	E Electric Field (volts meter)	H Magnetic Field (ampere turns per meter)	P_A Field Intensity (average power density in milliwatts per sq. centimeter)
200 - 525 kc s	300	0.5	
1.5 - 32 Mc 's	200	0.5	
100 - 162 Mc s			0.01
225 - 900 Mc 's			0.01
400 - 450 Mc 's			1.00

(b) Radar Systems

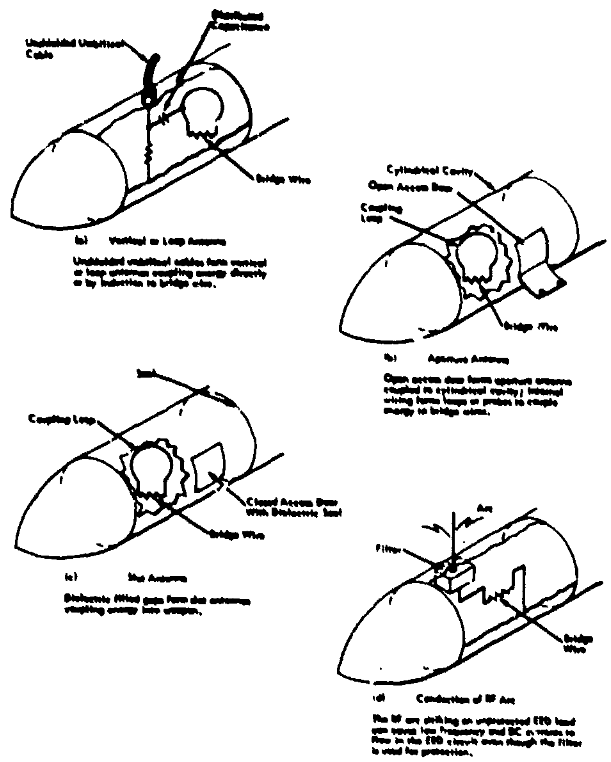
f Frequency Mc s	P_A Field Intensity (average) power density in milli-watts per sq. centimeter)
200 - 225	10
790 - 1400	1
2900 - 3700	50
5400 - 5900	100
1900 - 10700	130
13400 - 14000	120

Figure 14



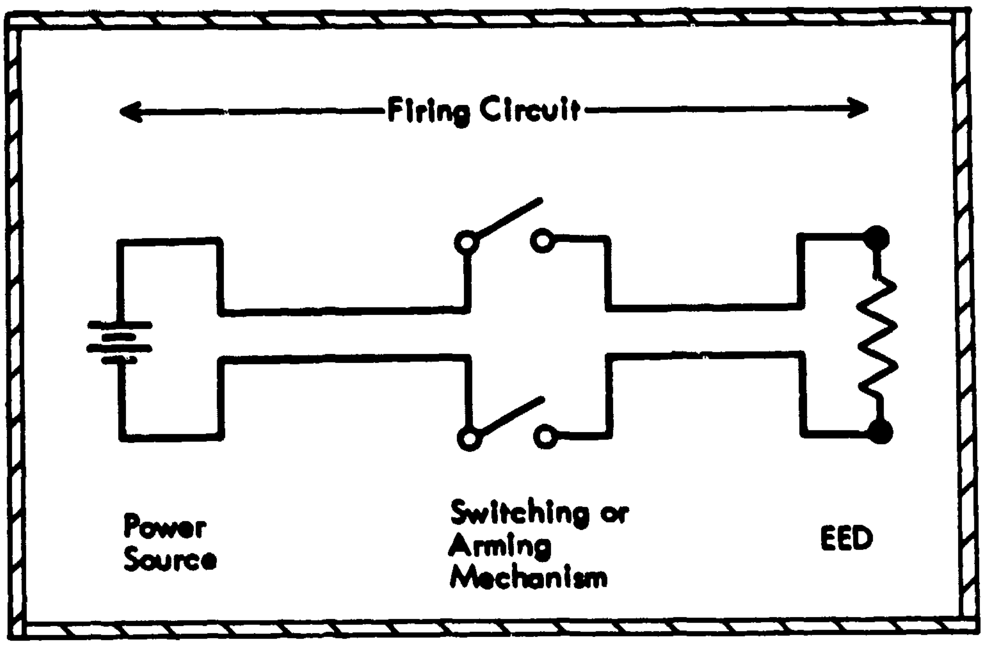
AN EED MATCHED TO A DIPOLE ANTENNA

Figure 15



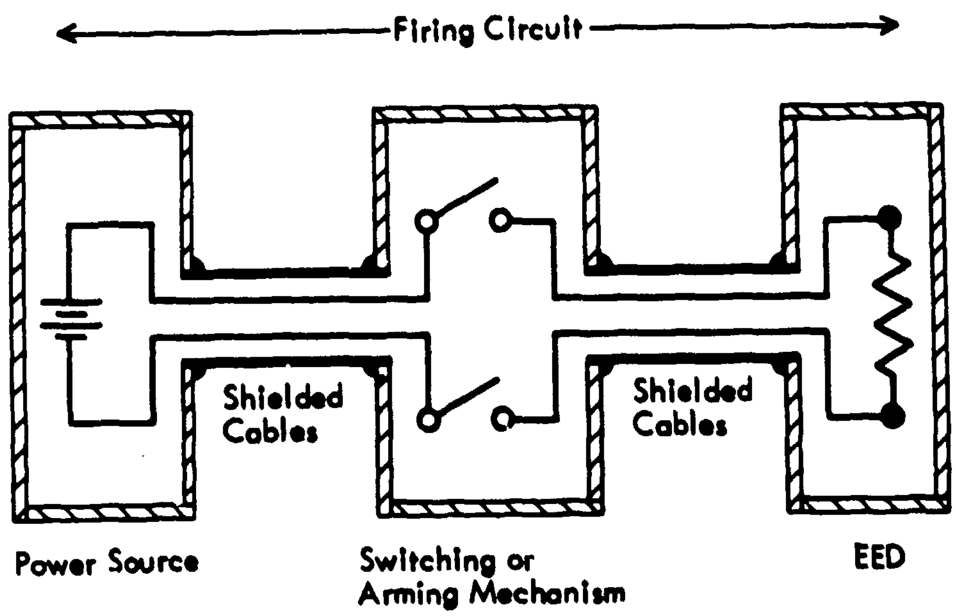
METHODS OF COUPLING BY ENERGY INTO A WEAPON

Figure 16



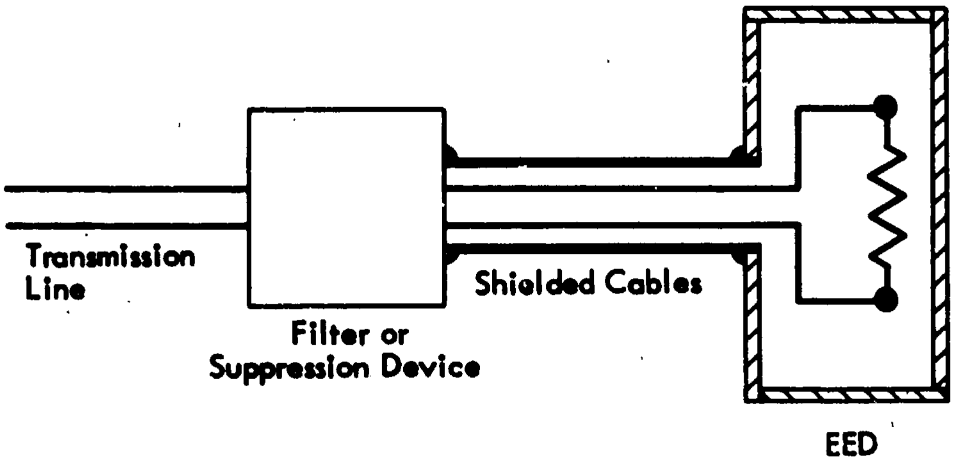
THE CONDUCTIVE BOX CONCEPT

Figure 17



COMPARTMENTALIZATION, AND SHIELDING OF COMPARTMENTS AND CONNECTIONS

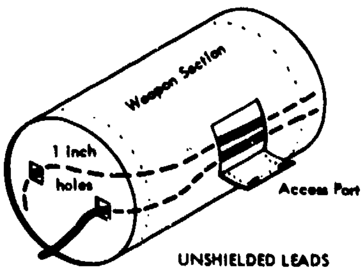
Figure 18



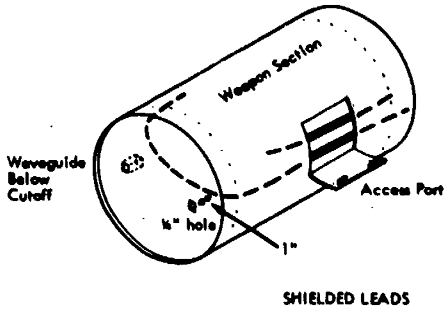
USE OF RF FILTER OR SUPPRESSION DEVICE

Figure 19

Unacceptable



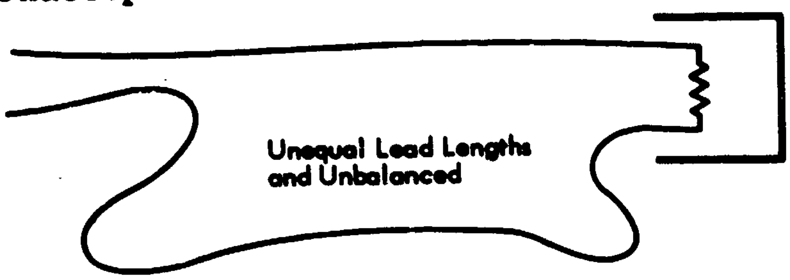
Acceptable



HOLES AND ACCESS PORTS IN WEAPON SECTIONS

Figure 20

Unacceptable



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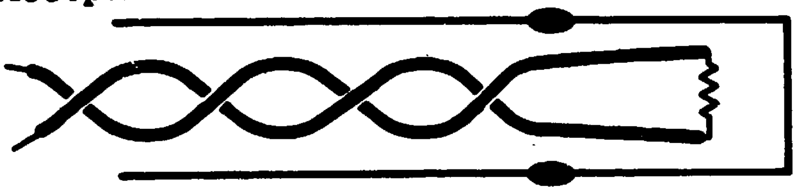
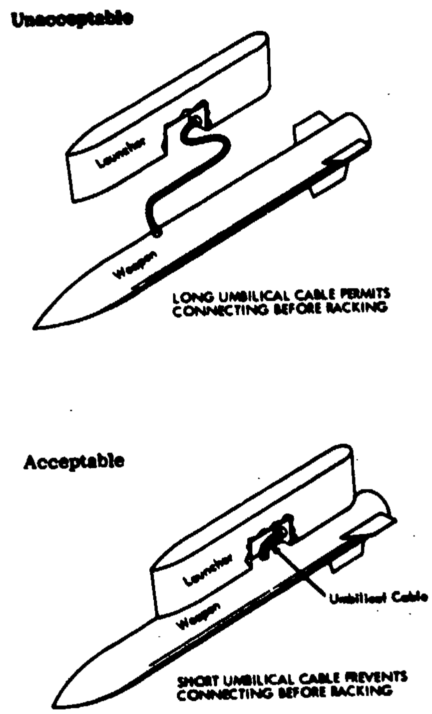


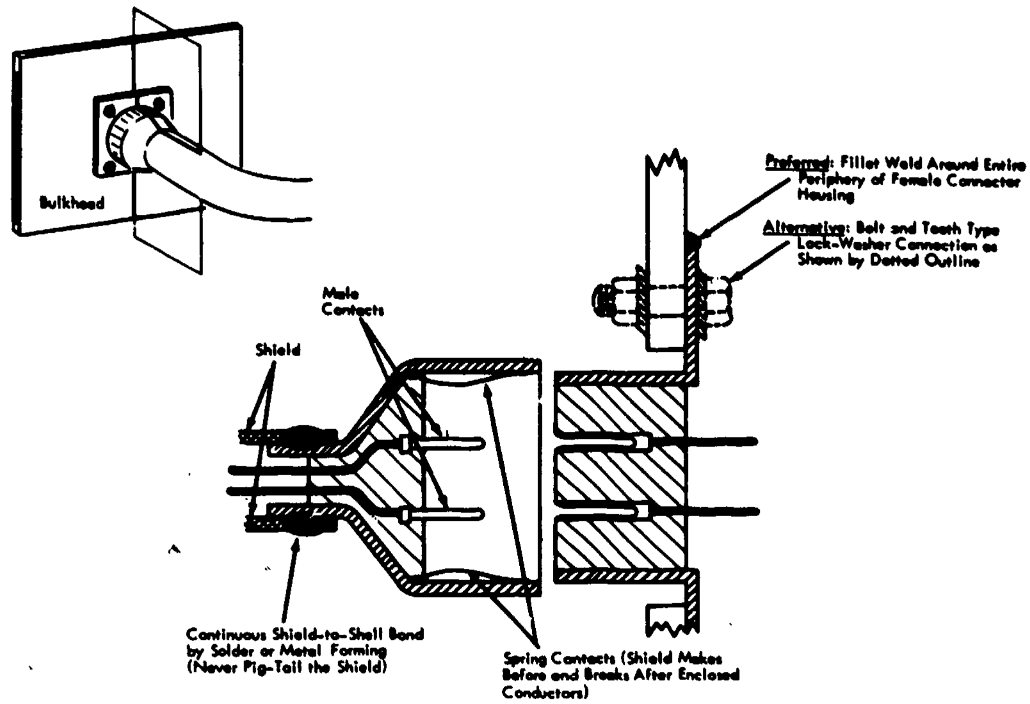
UNEQUAL LEAD LENGTHS AND TWISTED SHIELDED PAIR

Figure 21



WEAPON /LAUNCHER INTERFACE
AND UMBILICAL MATING

Figure 22



SHIELD TERMINATION FOR ELECTRICAL CONNECTORS

Figure 23

REVIEW OF PAPERS PRESENTED AT THE 5TH ELECTROEXPLOSIVE DEVICE SYMPOSIUM AT FIRL

E. E. VANLANDINGHAM, SESSION CHAIRMAN

E. E. HANNUM, PROGRAM CHAIRMAN

Problems associated with the safe and reliable use of electroexplosive devices and associated components have stimulated valuable thinking in the design, development, and subsequent usage of these units. At the recent 5th E.E.D. Symposium, the results of a number of research and development programs were presented. As can be seen from the brief review to follow, the electroexplosive units discussed are obviously designed to meet certain operational and functional requirements, however prime consideration has been given to safety associated with the use of the devices. The first paper to be discussed reviews the development of a 15-second delay squib by the McCormick-Selph Company under contract to Douglas Aircraft Company and was presented at the Symposium by Mr. Sid Moses of Douglas.

The failure of a Delta Space Vehicle flight in August of 1965 was traced to malfunction of a delay squib which caused premature ignition of the third-stage motor. The National Aeronautics and Space Administration, Goddard Space Flight Center (Goddard), decided to replace it with a new, high reliability device. Douglas Aircraft Company, Missile & Space Systems Division (Douglas) was contracted to prepare a specification for a new squib.

It was decided that the delay squib should be a single-circuit device rather than the more conventional two-circuit devices which have been popular. This was based on the conviction that the modern EED, having a flush bridge wire and a pressed prime, has virtually eliminated the broken bridge wire problem. With a single circuit EED, some weight saving could be achieved in the wiring system and possible circuit-to-circuit problems were eliminated.

Squib Characteristics

Goddard awarded a contract to McCormick-Selph of Hollister, California, for the development and qualification of this 15-second delay squib.

A schematic design is shown on Figure 1. For this development, McCormick-Selph utilized two interesting proprietary materials: (1) The initiating explosive around the bridge wire is a high-temperature stable, non-conductive material. Both the material and its residue combustion products are non-conductive. (2) The delay column is a pyrotechnic, prepackaged in a lead tube, which is then drawn to a diameter of less than 0.1 inch, designated by McCormick-Selph as Small Column Insulated Delay (SCID). The SCID in the 15-second delay squib is completely

gasless and has a deflagration rate of 14 seconds per foot. Based on the Development and Qualification Program, the squib has the following characteristics at 70°F.

A. When calculated at the 95 percent confidence level:

1. At least 99.9 percent of the squibs have a 5-minute no fire of 1.72 amperes (approximately 2.1 watts) which exceeds the no-fire safety requirement of 1.0 ampere (1.0 watt).

2. At least 99.9 percent of the squibs will have a delay of between 14.8 and 16.8 seconds.

B. When calculated at the 90 percent confidence level:

1. At least 99.9 percent of the squibs require a minimum all-fire current of 3.47 amperes for a 20 ms pulse.

2. The squib initiator has a demonstrated reliability of 99.36 percent when fired with a 4.0 ampere, 20 millisecond pulse based on 370 firings.

Degradation Tests

Test squibs were subjected to 25 applications of tests measuring insulation resistance, dielectric strength, and electrostatic discharge. In addition, test squibs were subjected to a current of 20 milliamperes for a period of 24 hours representing a small leakage through the electrical circuit. None of these tests degraded the firing characteristics of the squib. Test squibs were subjected to 25 cycles of the 1.0 ampere no-fire current. After this test, the squibs functioned in a normal manner. In subsequent tests, two initiators were subjected to 52 cycles of the no-fire current for 2-1/2 minutes followed by a 5-minute cooling period. After this test the initiators were functioned at 4.0 amperes. The bridge wire burnout time of 2.6 milliseconds for the squibs tested is comparable to an average of 2.4 milliseconds for the 72 qualification firings. McCormick-Selph stored the delay squibs at 160°F for 8 hours, 130°F for 72 hours and 112°F for 336 hours. The squibs were then fired in a 10 cc pressure chamber and behaved in a normal manner.

Electrostatic Protection

Because of a previous lethal accident caused by static electricity, extra precautions were taken in making this squib safe from electrostatic discharges (ESD). A review of ESD protection devices indicated to Goddard-Douglas that a preferential air gap between the electrical lead-in pins of the squib and the metal case appeared to offer the best protecti available. This allows an electrostatic spark to jump across a small air gap without passing through the explosive primer material around the bridge wire. In the production squib, this air gap was controlled to break down between 1000 and 3500 volts DC. A preferential air gap is protection only if it can be determined that it is preferential. That is, the primer material around the bridge wire must be insulated so that breakdown does not occur through this material. With development squibs, breakdown of the primer cavity did not occur at 10,000 VDC providing a factor of safety of at least 3:1 over the maximum breakdown of the preferential gap.

RF Sensitivity

As part of the development program, 270 initiators were sent to Franklin Institute for RF sensitivity tests.

As an additional safeguard against RF, a Douglas lossy line (skin effect) filter is installed on the squib in the spacecraft. This filter is similar to one described by Warner and Klamt at the Second HERO Congress in 1963. It provides from 10 to 80 DB protection over the frequency range from 0.1 to 10,000 MHz.

It appears that the time delay initiator developed under this program will offer an effective solution to the Delta programs operational requirements vehicle at the same time a high degree of safety is designed into the device.

The second paper to be discussed was presented by Mr. Louis J. Montesi of the Naval Ordnance Lab. and presents the results of further development work on a Water Arm-Air Safe Detonator originally developed by Stresau and Slie.

Current Navy design practice for explosive trains is to interrupt the action of the sensitive explosives between the initiator and the input to the lead and/or booster. The explosive action is interrupted to avoid accidents from unintentional initiation of the "sensitive" explosives in the train. This has previously been accomplished by interposition of barriers and/or by misalignment of the train components.

A second Navy requirement is that arming, or alignment of the displaced components, for example detonator to lead, be accomplished after launch. In underwater ordnance, such arming is usually accomplished by mechanical means, actuated by either water pressure or movement of the device through water.

A third Navy requirement is that any explosive used beyond the interrupter shall be no more sensitive than the Navy standard of tetryl.

An appealing approach to the development of systems which are to arm after water entry is to utilize the difference between the confining action of air and of water to control propagation of detonation. Stresau and Slie invented a "Water Confinement Arming Device" using the above differential confinement principle. This is a device which will propagate to detonation only when immersed in water. It does not depend on physical interruption of the column to prevent detonation propagation when in air. The detonator, as further refined by Stresau is shown in Figure 2.

The unique feature of this design is that a lightly confined column of explosive is surrounded by an annular air cavity and, in turn, by a relatively heavy metal tube. The diameter of the column of explosive is chosen so that it is less than the failure diameter when the annular cavity is filled with air, and larger than its failure diameter when this same cavity is filled with water. This change in "failure diameter" is the result of the greater effectiveness of water as a confining medium. This effect is further increased by the reflected shock wave from the surrounding tube.

Stresau in his original assessment of safety and reliability used a "no dent criterion" for a detonator failure in air. That is, when his device was initiated in air, explosives could propagate to and through the base charge, but could not produce any measurable dent in a steel witness block used to measure base charge output. However, this design when fired in air occasionally permitted complete burning of the base charge explosive.

The purpose of this report is to describe work at the Naval Ordnance Laboratory undertaken to further the development of an explosive device of this type.

a. Study feasibility of using higher density nitroguanidine to increase mechanical stability to vibrational forces.

b. Quench burning action when fired in air.

c. Verify confinement enhancement effect of steel jacket when in water.

d. Improve fabrication methods: shorter column, better plastic tubing material.

e. Make item capable of meeting usual surveillance conditions for explosive components, i.e., Mil-Std-304 temperature-humidity cycle.

A detailed report of the results of this investigation are given in Mr. Montesi's paper, however, a brief summary is as follows.

The first tests conducted were to determine the optimum charge density of the nitroguanidine transmission charge. It can be concluded from the results that the nitroguanidine transmission charge density should be less than 0.80 gm/cm and more than 0.35 gm/cm for reliable initiation of the base charge in water. As regards safety, or chance initiation of the base charge in air, no high order initiation of the base charge occurred over the entire density range.

In addition to these tests the propagation velocity of nitroguanidine at various densities was measured underwater using a 35 mm smear camera. The propagation velocities of nitroguanidine were measured in two test configurations: with and without the outer metal confining sleeve. As earlier stated it was suspected that the shock wave underwater was reinforced by the reflected shock wave from this confining tube. The results of these tests although inconclusive appear to support this suspicion. It is also evident that the propagation velocity increases as the density of the nitroguanidine transmission charge increases.

Tests were conducted to determine the optimum barrier thickness required for reliable detonation transfer in water. There were 54 out of 54 successful fires made with barriers ranging in thickness from 40 to 200 mils. Nineteen out of 19 fires were observed with a barrier thickness of 150 mils, a thickness nearly four times greater than the intended 40-mil design thickness.

The safety aspect of the WARAS Device tested in air were assessed using the VARICOMP test procedure. To prove that detonation will not propagate in air from nitroguanidine to the CH-6 base charge across the 40-mil thick aluminum more sensitive explosives--PETN and Calcium Stearate-RDX (1.65/98.35) were substituted--for the CH-6 below the aluminum barrier. It should be noted that only the CH-6 in the base charge is changed.

As an additional conservatism all of the safety tests were conducted with a thinner barrier than is intended in the final design, i.e., 25 mils instead of 40 mils.

Three types of quenching were noted: (a) somewhere in the nitroguanidine column leaving some unburned nitroguanidine, (b) somewhere in the intermediate CH-6 charge above the aluminum barrier leaving some unburned CH-6, and (c) quenching at the barrier with all explosives above the barrier being consumed. Only when the latter outcome was observed was there any chance of initiating the VARICOMP explosive.

The safety and reliability aspects of the WARAS Detonator were deemed acceptable with a 40-mil thick aluminum barrier.

The device did not pass the temperature-humidity test, a concentrated effort in that direction is being made.

Leakage was traced to: (a) poor epoxy seals, (b) pin holes in the tube (it seems that it is possible to get pin holes in tubes of 2 mils wall thickness), (c) tube punctures during loading.

It appears essential to either increase the wall thickness of the tubing or have inspection techniques that will preclude the acceptance of tubing having pin holes or other leaks. Since damage to the tubes may occur during the loading process the use of thicker tubes is going to be investigated. The use of a thicker tube will necessitate a reconfirmation of the safety and reliability estimates already made.

An entirely different approach to the design of electroexplosive devices was given in a paper presented by Mr. D. J. Lewis of the Space Ordnance Systems Company.

Laser Energized Explosive Device

On the basis of several preliminary experiments utilizing a laser to initiate explosives, the Space Ordnance System Company decided to investigate laser-energized systems. The reasons were: if explosives could be initiated using coherent light as a source of energy and a means found to transmit it to various components (detonators, initiators, igniters, etc.), one could not only eliminate the RF, electrostatic, and EMI problems, but might possibly arrive at a system that was a great deal simpler in design.

The LEED system (Laser Energized Explosive Device) eliminates the use of all connecting metallic lines, bridge wires, spark gaps, ceramic headers, etc. The laser source creates an energy pulse which is transmitted via non-metallic, fiber optic conductors directly to the pyrotechnic compound to produce the required reaction. A schematic of this unit is shown in Figure 3.

A simplified but informative explanation of the operation of lasers in general and the specific application of lasers and fiber optics to this concept is given in Mr. Lewis's paper.

The initiator used with the LEED system looks exactly like a normal EBW or hot bridge wire unit on the outside. It is however, extremely simple in design. All bridge wires, spark gaps, pins, ceramic headers,

insulators, etc., have been eliminated and the device simply contains the explosive compound sealed in by means of a glass window. The glass itself is a high quality infrared transmitting glass with tapered conical shaped edges which recollimates the laser beam being received from the optical fiber and loads the window optimally. The windows are designed, and have been tested, to withstand up to 100,000 psi and allow the application of laser light on the explosive compound over a 0.01-inch squared area.

One of the most interesting features of the LEED system is the ease of connecting the optical fibers to the end-users: detonators, initiators, etc. The system does not require any special methods of optical fiber end-coating, grinding, or special geometry, and the optical fiber ends can be cut and mated to the connector in simple fashion.

The connectors do not have to be water or moisture tight since these environments do not effect the transmission of energy from the donor to the receiving fiber.

The LEED system is completely insensitive to RF and electrostatic energies. The only physical connection to a detonator or initiator, or group of these devices, is the series of optical fibers. The coherent light moves, independently of these fields, to the explosive device and causes the pyrotechnic reaction. Since the optical fibers and the ordnance devices are immune to reaction of these fields (they contain no electrical circuitry or are pure Faraday shields; radiation has no means by which it can produce effects), the system is completely safe and reliable.

Accidently setting off the LEED system by means of extraneous light sources is very nearly impossible for the following reasons:

a. High intensity non-coherent sources are very nearly non-existent. Test with output energy as high as 5000 joules, using non-coherent sources, have been focused into the fibers and have not set off any reaction.

b. Due to the characteristics of the fiber optics, unless the energy it is transmitting is coherent, the phenomenon necessary for pyrotechnic reaction will not be present and since there is no naturally coherent sources, the hazard is eliminated.

c. The fiber is totally internally reflecting and, hence, is totally externally reflecting. Therefore, no energy will be received by the fiber unless it is within the acceptance angle of the fiber which is below 9 degrees.

It can be seen that a very high intensity light (higher than the flux density of the surface of the sun) that is coherent, at the right frequency to transmit efficiently down the fiber, and within the acceptance angle of the fiber must be used.

The LEED system power supply is adaptable to the normal electrical systems used in aircraft, missiles, and spacecraft. The system operates in a similar fashion to an EBW system.

A low voltage source, i.e., DC battery or 400 cycles AC, is used as input energy. This is then stepped up to a higher voltage and charged into a capacitor. The capacitor is then "dumped" into the optical pumping source, which may be a xenon flashlamp, to create the necessary population inversion in the ruby or neodymium rod. Basically, the system is a low voltage, to high voltage stepup, to energy storage, and then via an electrical switch, to the flashlamp.

Following further development this concept could offer an attractive solution to many of the operational and safety problems currently being experienced in missile systems.

An area of definite concern to users of electroexplosive devices is the stability of RDX in shape charge since this is a system often used in conjunction with EEDs. The results of an interesting study in this regards were presented by Dr. N. J. Bowman and Mr. E. F. Knippenberg of the General Electric Company.

Within recent years flexible linear shaped charge (FLSC) has received widespread acceptance within the aerospace industry and is currently being used in a number of missile and spacecraft systems. Use of FLSC in missile stage separation applications offers several important design advantages. In particular, its use generally results in significantly lighter weight structures as compared to alternate systems.

FLSC contains a continuous core of high explosive encased in a thin metal sheath. Almost all FLSC manufactured and utilized to date consists of an RDX explosive core in a lead alloy sheath. Originally FLSC was fabricated with a cardiod cross-sectional shape. More recently a chevron shape has been employed, as it was found to give significantly improved cutting performance. While the chevron shape is optimum from an explosives performance standpoint, it is somewhat fragile from a mechanical point of view. In particular the thin metal sheath of this configuration has been found to be easily distorted by internal gas pressure generated during storage or testing at elevated temperatures. When subjected to increasing internal pressure, the chevron shape has been found to gradually deform into a shape approaching a triangle. With the loss of the chevron shape, the cutting ability drastically degrades.

In actual applications the shaped charge is provided with end-seals to prevent moisture from being absorbed into the RDX core since this

can destroy the detonating properties of RDX. Thus, any chemical instabilities of the FLSC constituents, or of the end-seal materials, result in the generation of gases which will gradually distort the chevron shape and degrade its cutting properties. Therefore, it is essential that the ingredients and sealing materials used in the FLSC possess a high degree of chemical stability at elevated temperatures.

In order to study the variables involved in thermal stability of RDX, two samples of this explosive were obtained from the Canadian Arsenal, Ltd. The first sample was designated as Type B indicating that it was made by the Bachman process which utilizes acetic anhydride as the nitration medium. This results in the formation of from 8 to 10% of HMX as a bi-product.

The second sample, normally referred to as Type A RDX, was made by the British process which uses only nitric acid and results in less than 1% of HMX being formed.

There were a wide variety of theories as to the cause of the instability found in shaped charge made from RDX. They can be divided into classes and each was studied experimentally and most of them eliminated. The general classes are as follows:

1. Sheath materials and/or moisture. The usual material for shaped charge sheath is antimonial lead but pure lead and aluminum have also been used. Moisture may enter into the reaction postulated between RDX and the sheath material.

2. Additives

3. Materials used in making adequate end-seals in shaped charge systems.

4. Impurities in the RDX.

The Bowman-Knippenberg study produced the following:

1. The lead-water-RDX interaction does lead to the evolution of gas, but at a very slow rate. The ballooning of shaped charge cannot be explained on the basis of this reaction alone. The following was also found:

   a. An increase in the percentage of lead (surface area of contact) causes an increase in the rate of gas evolution.

   b. An increase in the percentage of water leads to an increase in the rate of gas evolution.

2. Hydrogen, even if formed by the reaction of lead and water, does not react with RDX appreciably to form volatile amines.

3. The presence of aluminum of the type used in sheath materials, does not lead to evolution of gas. Aluminum is several times as strong as lead (tensile strength roughly ten times as high) and it was not possible to get ballooning even at 350°F as the end-seals consistently failed first. It is therefore concluded that, with aluminum sheathed shaped charge, ballooning will not occur until a high internal pressure has been generated. It is probable that the seals will fail before this necessary pressure is reached.

4. Any PbO formed by the reaction of water and lead does not act to accelerate the decomposition of RDX.

5. The presence of HMX has no effect on the stability of RDX.

6. Duponol (an antistatic agent) in the amounts usually present causes only a slight increase in gas evolution. Duponol in gross amounts is known to lead to thermal instability.

7. Rhodamine (a dye) in the amounts usually present in shaped charge does not affect thermal stability of RDX.

8. No fibers were found in the raw RDX upon microscopic examination of the two samples that were available. From this it has been concluded that raw RDX is thermally unstable even in the absence of fibers, although undoubtedly it is less stable if cellulose fibers are present (as has been reported).

9. M and P-100 (the epoxy resin presently used in Mark-6 shaped charge assemblies) will cause rapid gas evolution IF IT COMES IN CONTACT WITH THE RDX CORE. This may occur through faulty preparation of the assemblies. Vapor contact is to be avoided particularly with over catalyzed M and P-100 which will contain free TETA.

10. Other epoxys tested as replacements for the M and P include: Metagrip, CONAP, Armstrong C7 and Scotchcast No. 10. CONAP, even in direct contact with RDX, envolved only a small amount of gas. However, its physical properties (flexibility particularly) make it undesirable for use. The second best from a gas evolution standpoint was Scotchcast No. 10. It has acceptable physical properties and its use is recommended.

11. The largest part of the thermal instability of "raw" RDX comes from the impurities which it contains. There are at least 50 of them and it is impossible to identify any particular ones that are detrimental. The chances are that many of the possible impurities have poorer stability than the RDX itself. There are others, notably HMX, which are more stable.

It has been shown, both by isoteniscope-gas evolution tests and forced ballooning tests on shaped charge itself, that these impurities can be removed by recrystallization from acetone. It is important to note that a TRUE RECRYSTALLIZATION is required using differential solubility and no water in any form. The term recrystallization is used in the explosives industry to include a variety of processes in which water is added while cooling or evaporating.

12. It is necessary to dry the RDX at elevated temperatures (65°C to 80°C) under reduced pressure with a stream of DRY air flowing over the surface or through it. This is required for two reasons. First calculations have shown that if the water content is above 0.2%, ballooning of the 15 grain, lead sheathed shaped charge may occur due to the vapor pressure of the water alone. Secondly, if this is not done the RDX may not be dried homogeneously and local concentrations of water several times the average value may be found.

13. By use of highly purified RDX, keeping the water content of the RDX below 0.2%, and using improved end-seal materials, shaped charge can be made that is stable indefinitely at temperatures to 240°F.

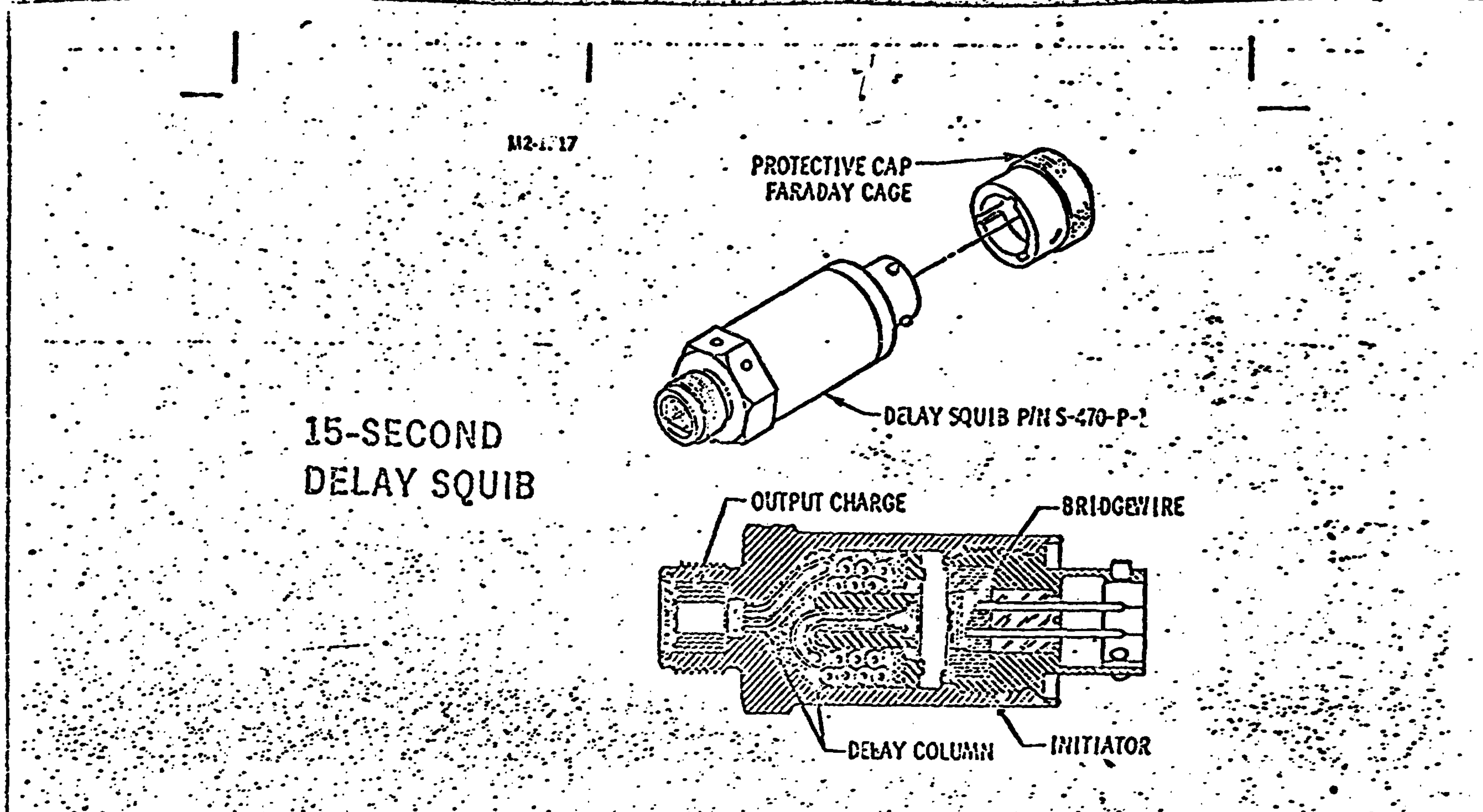
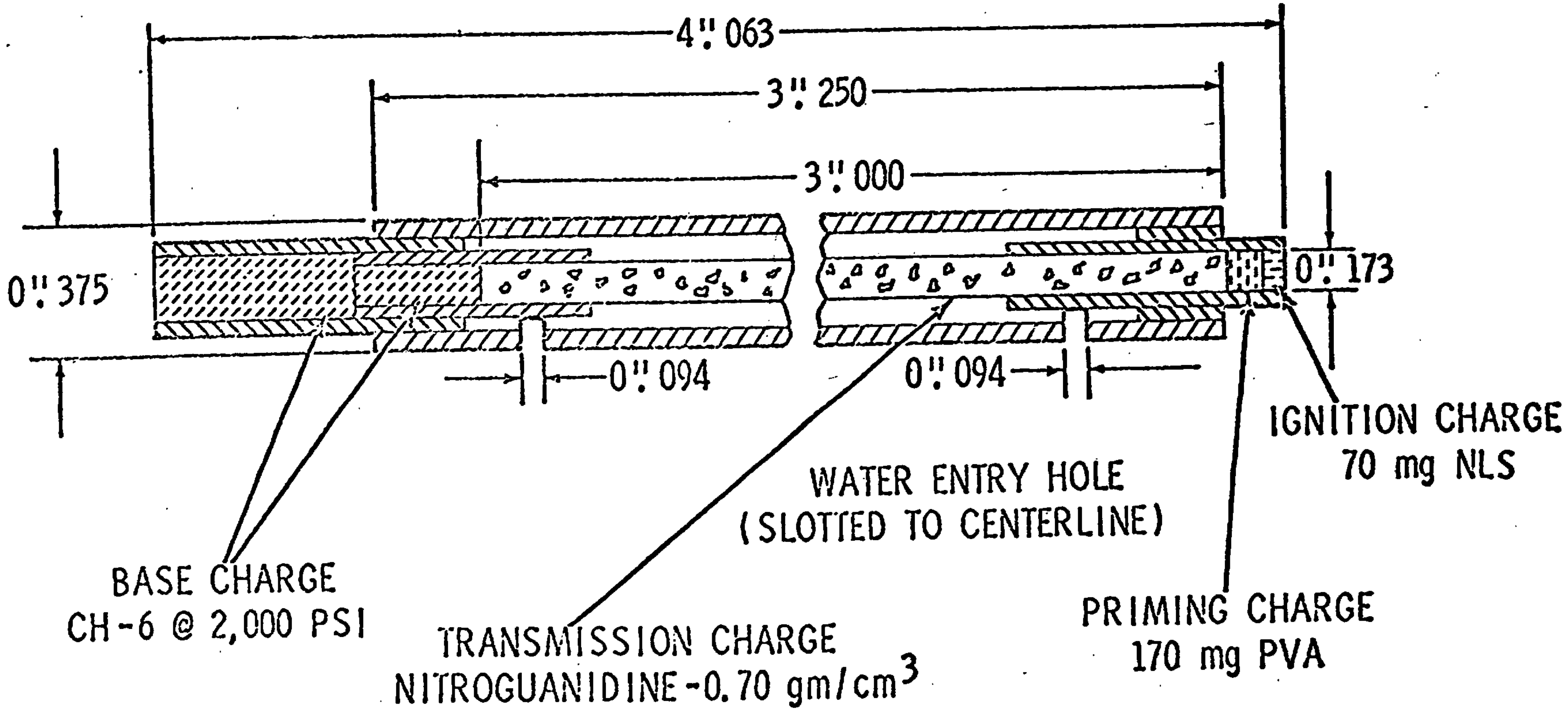


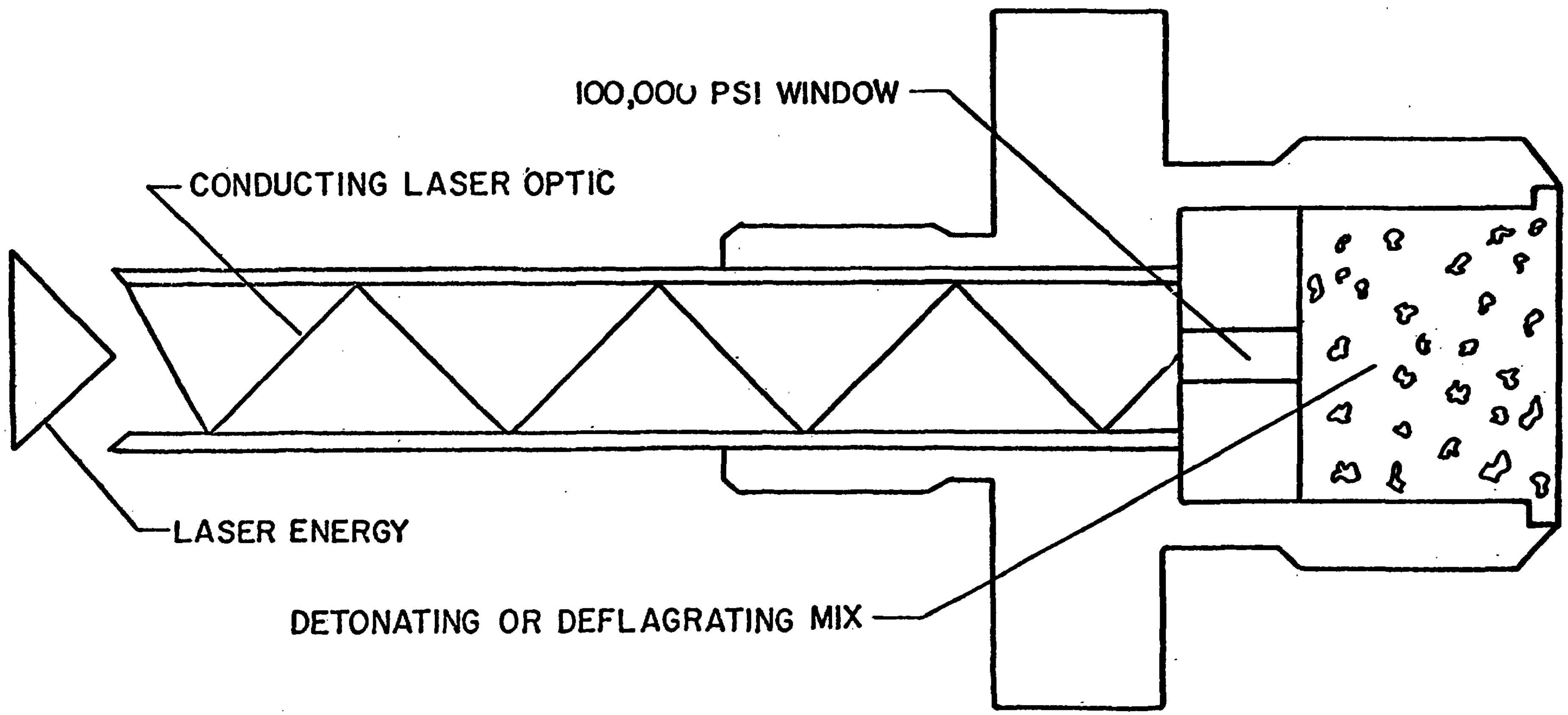
Figure 1. 15–Second Deley Squib

Fig. 2.

WATER CONFINEMENT ARMING DEVICE
(STRESAU TYPE K160)



LASER ENERGIZED EXPLOSIVE DEVICE



Hazards to EEDs in Shipping and Handling With Emphasis on Lightning, Static, and RF Electricity

By Chas T. Davey

Introduction

Current packaging practices for electroexplosive devices (EEDs) must be reasonably safe because we hear little about them exploding in shipment and their failure rate appears to be low in use. But it pays to ask how far we are from an accident or from a point where the subsequent performance may be affected. It was for these reasons, safety and reliability, that a packaging study of small electroexplosive devices was undertaken.[1]

Some of the factors that can influence electric initiators are shown in Figure 1. There are probably others that are not shown as well as subdivisions and of course various combinations of factors.

As far as shipping and handling are concerned, some of these factors can be quickly dismissed from this presentation. Nuclear effects, for example, appear to require four orders of magnitude higher than the human lethal radiation dose for adverse effects.[2] Chemical effects, unless the explosive materials are themselves incompatible, would have to penetrate the case header or the seals between them. Biological influences, fungus, bacteria, and spores usually require moisture and warmth in order to cause damage (which does not appear to be too serious a problem in this country).

Mechanical effects including those listed at the top of Figure 1 require some additional study, particularly defining the level at which impact damage begins to occur. Other considerations were given to the effects of blast and accompanying particles in the original work on this project as well as for the shipping environment, which for normal conditions is not severe. One of the major points of interest in mechanical considerations is the lack of ICC requirements on dunnage for items that do not have an explosive output.[3] Main concern with ICC regulations is for the safety of the carrier and the general public.

Heat does not appear to be a real problem in transportation for two reasons. First the ignition temperatures of explosives is relatively high,[4] and second, the temperatures that normally exist in transporation and storage do not approach the ignition temperature of the explosive.[5]

Most accidents involving EEDs are believed to be caused by electric ignition including lightning, static, and RF. These driving forces were examined in some depth in light of existing packaging and handling methods, mainly in a literature search.

(1) References are contained at the end of this paper.

EEDs are designed to fire when the bridge is heated electrically. However, other modes of firing can occur, as is shown in Figure 2, and often with far less energy than is required in the normal firing mode. Initiation in these other modes is generally due to sparking in, near, or through the explosive material but can sometimes occur at voltages too low to cause sparks or arcs as in the case where conductive mixes are used.

A logical step at this point is to look into the spark energies necessary to fire explosive materials. Figure 3 shows energies for some popular materials.(6) Note particularly from this figure the location of fulminate of mercury-potassium chlorate -50% firing energy of about 0.1 joule.

Now lets look at another source of information, Figure 4.(7) Note here that pure fulminate of mercury is shown to require only 0.0068 joule and that the value varies with the series resistance and confinement. Note also that there are wide variations in the sensitivity of other explosive materials under different conditions of preparation and test. Test and preparation methods may vary widely, but it seems important to note all materials exhibit a maximum spark energy sensitivity at a particular value of series resistance for each material is shown in Figure 5. Some of the series resistances for minimum ignition energy are quite high approaching insulation leakage resistances. The energy levels are often very low and in one case (lead styphnate) the critical series resistance is zero.

In practice it is not unlikely to have situations where static electric voltages are impressed on explosive materials where the resistance in series with the impending spark path thru the explosive corresponds to the critical resistance for maximum sensitivity (i.e., minimum ignition energy).

At present there is not evidence to point out whether or not this phenomenon carries over to electric initiators. It is believed that the spark discharge is the mechanism for static initiation of many EEDs. We know that there is a wide range of static sensitivities of the EEDs themselves and that some have fired most unexpectedly. Narrow gaps between the bridge element and the case appear to increase static sensitivity as do sharp projections on other elements.

Most testing for static sensitivity today is done using circuits that are believed representative of personnel borne charges.(8) We know that there are static electricity hazard conditions that do not involve the human circuit and these need better definition. Some of the more sensitive EEDs in the past have fired with only a few kV applied from the human circuit consisting of a 500-picofarad capacitor and a 5000-ohm series resistor to which the EED is connected.

Lightning is another source of potential difficulty through five main areas that may cause intense heating of the explosive around the bridgewire. These are

(1) The static field from the cloud center.

(2) The rapidly changing electric field during the dynamic processes in the lightning discharge.

(3) The magnetic field resulting from return strokes.

(4) A ground gradient caused by the main stroke.

(5) The direct strike with conduction of the main stroke current.

Fields of hundreds of kilovolts per meter are produced by lightning storms overhead. Figure 6 illustrates these fields as a function of distance from the vertical projection of the storm center for average conditions.[9] This field above can produce sparking between grounded and ungrounded objects and corona from sharp projections including lead wires of EEDs.

Figure 7 shows the electric fields that exist as a result of leader formation and then with the formation of a main or return stroke. Sparking has been observed at distances up to 1/2 mile from this kind of a stroke, and sparks between nails in wooden barns are believed to have started fires. Why not sparks between leads and case of EEDs?

The magnetic field from the main stroke is intense as is shown in Figure 8.[10] Here the magnetic flux lines link any loops in the EED and induce a potential in the loop. A current flows in the circuit of which the bridge wire is a part. These potentials, depending upon the stroke current, velocity, and distance as well as the loop area and EED sensitivity could add up to firing of an EED. This is not a weak field that is easily discouraged. Figure 9 shows estimates of the induced potentials for different loop sizes and for various distances from a stroke.

Another potential trouble point is the radial electric field that is produced in the earth as a result of a main stroke. Figure 10 illustrates the effect. The radial field and its magnitude for earth with three different values of resistivity are shown. Trouble here comes from any connection to different parts of the earth. The direct strike is nearly self explanatory.

The RF hazard requires a peculiar set of circumstances to be bothersome. Generally an aperture approach is used in hazard analysis.[11],[12],[13] Equivalent circuit and equations are shown in Figure 11 for general analysis. The aperture (A) in square meters is defined as the ratio of the power (W) watts delivered to load to the ambient power density (P) watts per square meter.

For worst-case analysis, the losses are considered zero and a perfect conjugate match is assumed to exist between the load and the internal impedance of the antenna.

Always one question arises, and that is what antenna shall we consider. This has a large influence on aperture because directivity is related to aperture (Equation 2, Figure 11).

The Air Force Eastern Test Range has considered the antennas that have extremely large directivity, the loop, the long wire, and the rhombic ($D = 1.3\lambda$).[14] It is not likely that any antenna formed in practice will have directivity exceeding these.

Packaged EEDs are usually either of the connector type or the twin lead type. Normally the leads are shorted in any case and aperture calculations for the general type of connector EED shows little potential hazard in fields as strong as 100 watts per square meter. Shorted lead wire EEDs on the other hand could present quite a problem under ideal circumstances. If, for example, a lead area of 0.002 square meter (formed by a square roughly 0.045 meter on a side) were exposed to a field with a frequency of 600 MHz, the effective aperture of this system would be about 0.25 square meter (assuming a load resistance of 1 ohm). The power delivered to the load is simply the product of the aperture and the power density. In the case of power density of 100 watts/square meter there would be 25 watts dissipated to the load. This is computed by Equation 3, Figure 11.

It may appear that this type of analysis is unrealistic; however in some instances the agreement between this method of analysis and values of aperture actually measured in the field has been within one order of magnitude or even closer.[15] The method will show that a system is safe if it is safe, but if the method does not show the system to be safe, it does not necessarily mean there is a hazard.

This situation arises from the fact that in the worst case analysis any unknown quantities in the various equations are assigned values that tend to maximize the apertures. This conservative approach almost certainly involves safety margins but the actual value of the over-all safety margin cannot be determined.

A better method of assessing RF hazards is needed, but because of the great number of complex, unknown, and unmeasurable variables involved there is little hope that a better method will be evolved in the near future.

In the packaged state initiators usually have a small loop area and problems with induced emf are minimal. Seldom would the aperture be expected to exceed 0.01 square meter. It appeared that most lead lengths are around 0.23 meter or less in the folded state and that the frequencies that are required to produce large apertures would need to

be in the L band or even higher. Electromagnetic energy at these frequencies is generally reflected by materials such as wood and other packaging material to some degree. Even without additional protection, it does not appear that the accidental initiation of packaged initiators would be a frequent occurrence from RF excitation. This is also the observed condition.

The previous example of the loop, however, shows that the effective aperture for relatively small loops can become quite large. The magnetic field resulting from lightning discharges will receive practically no attenuation from the present techniques used for packaging.

Some of the dunnage materials currently in use may be good static producers.

When all of these factors on the negative side of EED safety are considered, we must admit that the energies being fed the EED are probably approaching the lower end of the firing distribution at least part of the time even in the package. In handling, the situation is probably much worse and more unpredictable because the configuration and other factors are under constant change. How do we solve this problem?

Right away, we can begin by wrapping EEDs and their leads in metal foil. This will provide protection from the static fields and from some of the dynamic electric fields. This is an interim measure because this will not help much with the magnetic fields from lightning and VLF transmitters. It would be well to design an enclosure that will protect devices during shipment and during some of the handling operations. This is now viewed as an iron or steel container that will provide a large attenuation by absorption, about 4 DB per mil at 10 kHz. Copper flashing of the outside of the container will provide additional attenuation due to reflection, about 40 DB at 10 kHz.

One of the best solutions to the handling problem is to assure that the environment is safe by the following procedures:

(1) For lightning, stop operations when a storm is near and place all EEDs in steel containers.

(2) For RF, establish that the environment is safe by survey of the area either with calculations showing the ambient power density and frequency or by measurements showing the same thing. Then make a worst-case analysis of the devices being used. This will point up the needs.

(3) For static, handle devices in an area where all objects in the area are grounded and bonded together. The operator should be grounded preferably with wrist straps and should wear clothing that is not static producing, i.e., treated cotton.

EEDs are really remarkable. They can do so much work and perform reliably with little starting impetus. All of us are responsible for supplying them with a suitable environment when we don't want them to function or be affected. Not all of the problems involved with them with respect to safety have been solved, but with some consideration of their properties and sensitivity, they can be shipped, handled, and used safely and reliably.

Acknowledgements

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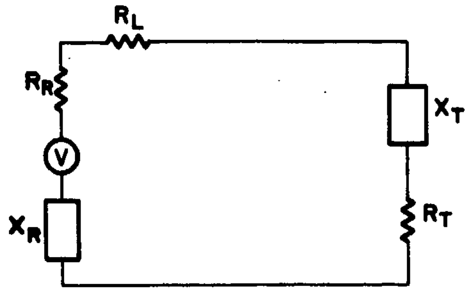


EQUIVALENT ANTENNA CIRCUIT

$$1)\quad A_e = \frac{V^2 R_T}{P\left[(R_R + R_L + R_T)^2 + (X_R + X_T)^2\right]}$$

$$2)\quad A_{em} = \frac{D\lambda^2}{4\pi} = \frac{W_{max}}{P}$$

$$3)\quad A_e = \frac{4.67 \times 10^4 A^2}{\pi \lambda^2 R_T}$$

V = THE TOTAL VOLTAGE INDUCED IN THE ANTENNA
R_R = RADIATION RESISTANCE
R_L = LOSS RESISTANCE OF THE ANTENNA
R_T = TERMINATION RESISTANCE
X_T = TERMINATION REACTANCE
X_R = ANTENNA REACTANCE
A_e = EFFECTIVE APERTURE (SQUARE METERS)
P = POWER DENSITY (WATTS/SQUARE METER)
W = POWER DISSIPATED IN THE ANTENNA LOAD
A_{em} = MAXIMUM EFFECTIVE APERTURE (SQUARE METERS)
D = DIRECTIVITY
A = AREA (SQUARE METERS)

Fig. 11 - Elements of the Aperture Approach to Worst Case RF Analysis

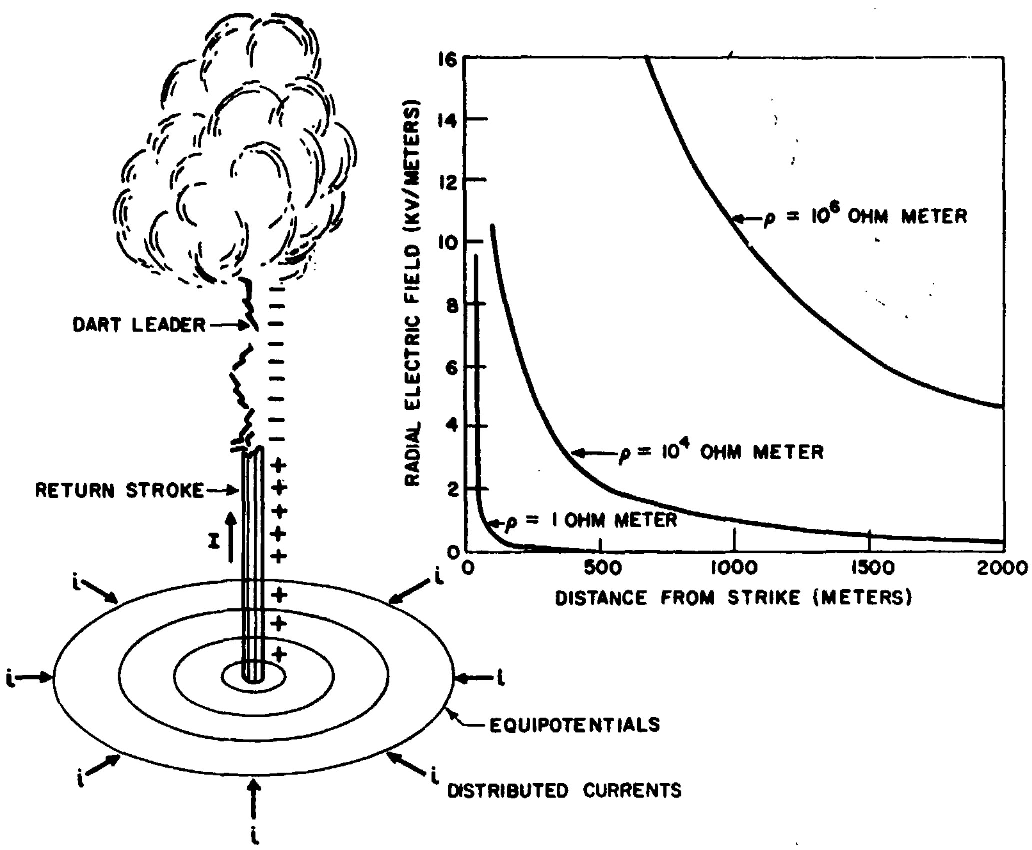


Fig. 10 - Radial Electric Field in the Earth Surrounding a Lightning Strike

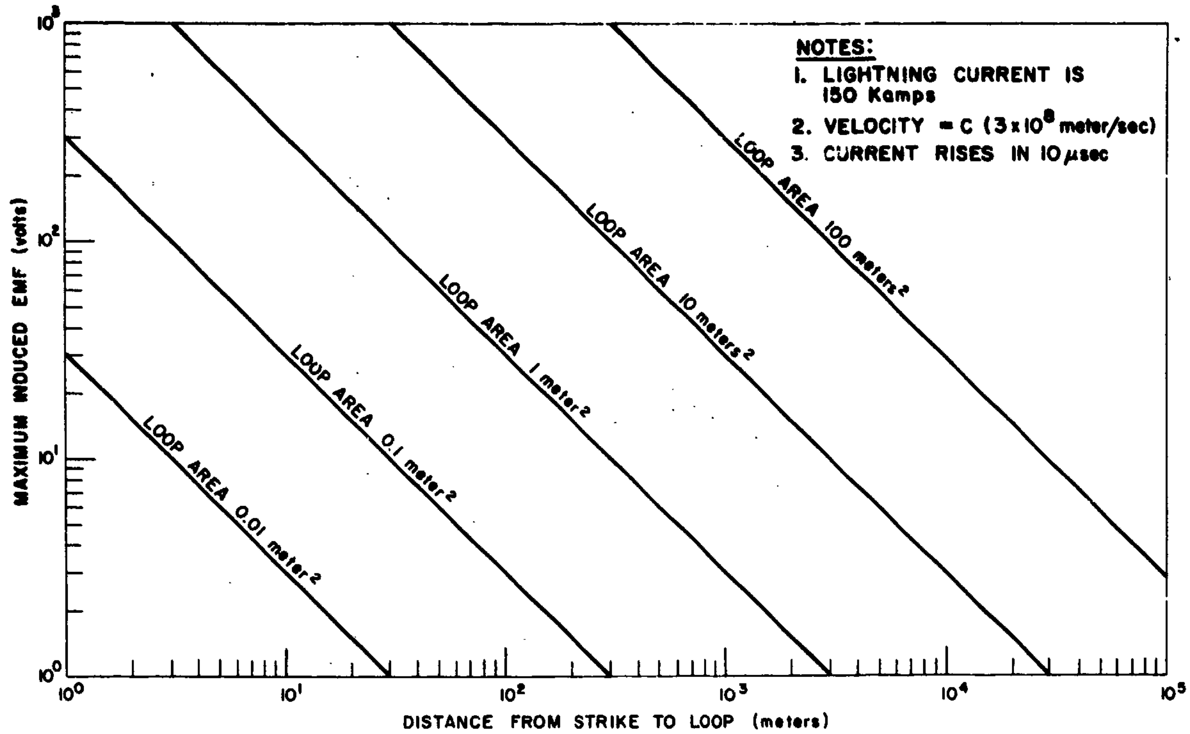
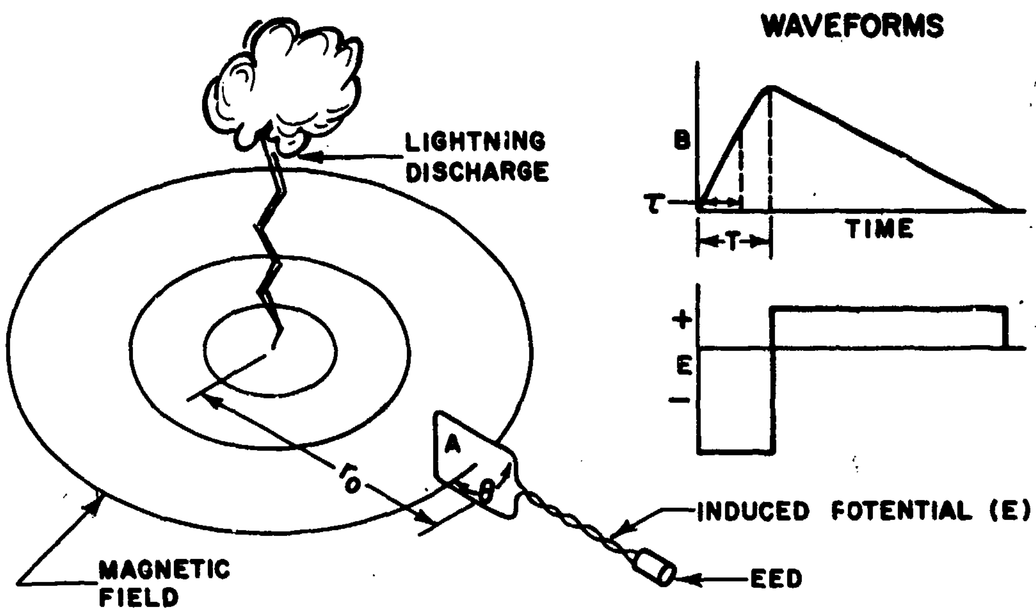


Fig. 9 - Estimated Maximum Potentials Induced in Loops by Lightning Discharges



$$P = \frac{2Z_{\wedge} I_0 V \tau}{{}_0 T}$$

$$E = \frac{-d\int_s \bar{B}\cdot d\bar{S}}{dt} = \frac{-dB}{dt} A \sin\theta$$

Fig. 8 - Summary of the Effects of the Magnetic Field from a Lightning Discharge on Electric Initiators

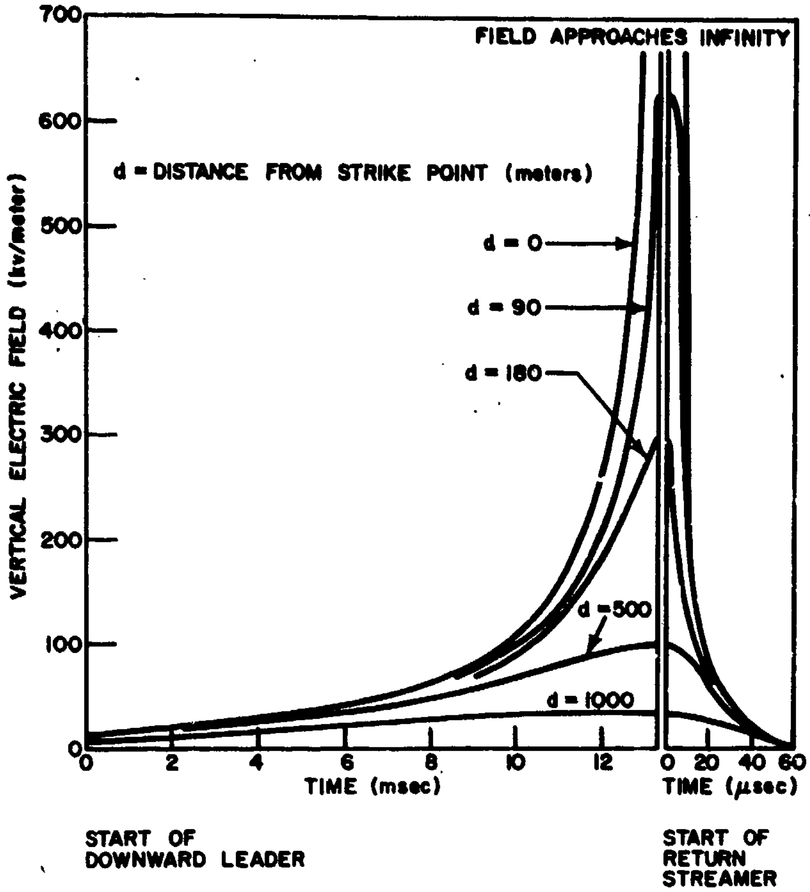


Fig. 7 - Vertical Electric Field During Dynamic Portions of the Lightning Discharge

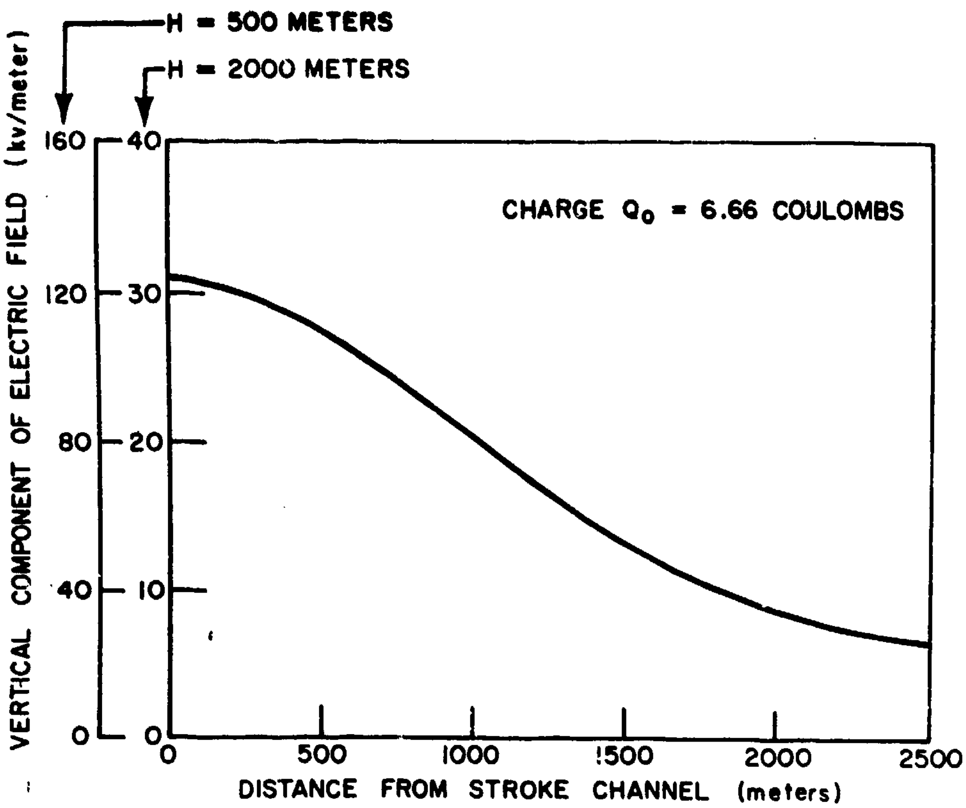


Fig. 6 - Static Electric Field Preceding a Thunderstorm

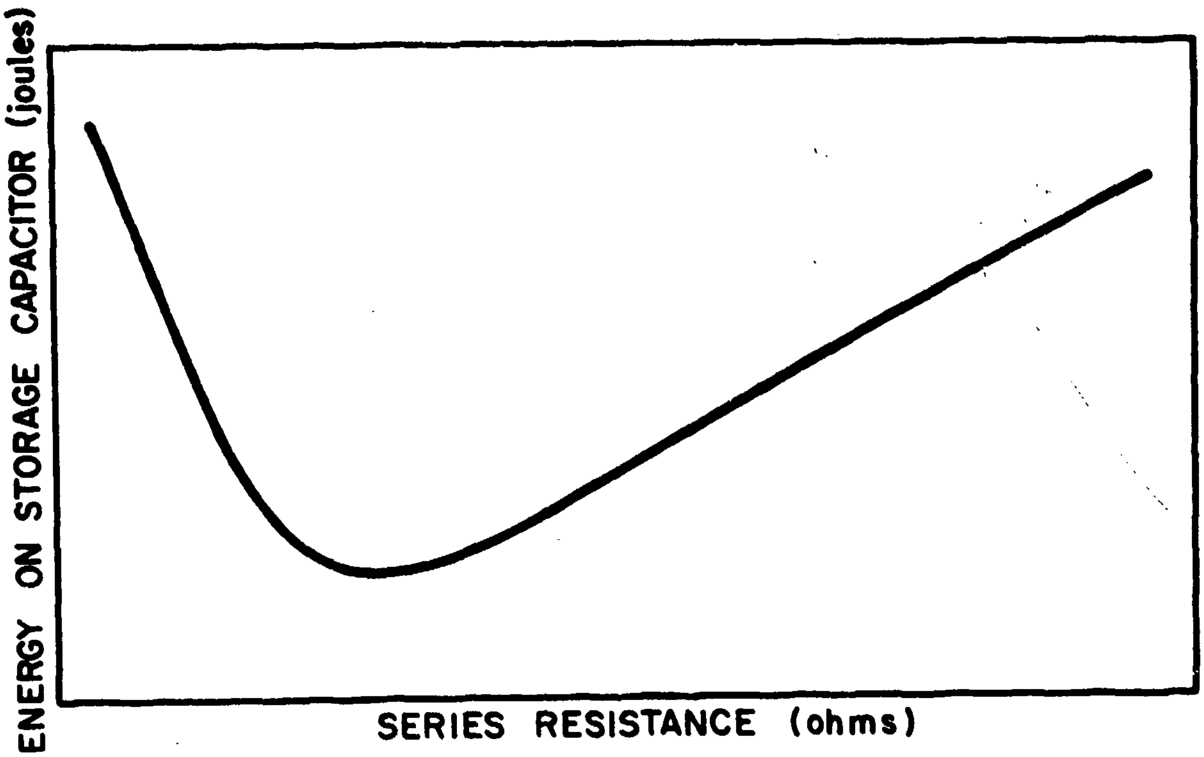


Fig. 5 - Response of Typical Explosive Material to Spark Gap with Series Resistance

Fig. 4 MINIMUM ENERGIES FOR IGNITION OF VARIOUS EXPLOSIVE MATERIALS

Material	Comments on Preparation or Testing	Minimum Energy on Firing Capacitor (Ergs)
Copper Acetylide		20
Lead Styphnate	Basic Preparation (chemically)	30
	Normal; Energy measurement depends upon experimenter	140 to 9000
	Prepared in humidity less than 0.1%	3.8
	Prepared in humidity less than 1.8%	112.5
	Graphite added in amount of 1%	0.6
Lead Azide	Crystalline	400 to 18,000
	Dextrinated	70,000 to 280,000
Lead Dinitro-resorcinate		500
Mercury Fulminate	Unconfined	800,000
	Confined	200,000 to 250,000
	Series Resistance of 5,000 ohms	68,000
	Series Resistance of 25,000 to 750,000 ohms	100,000 to 280,000

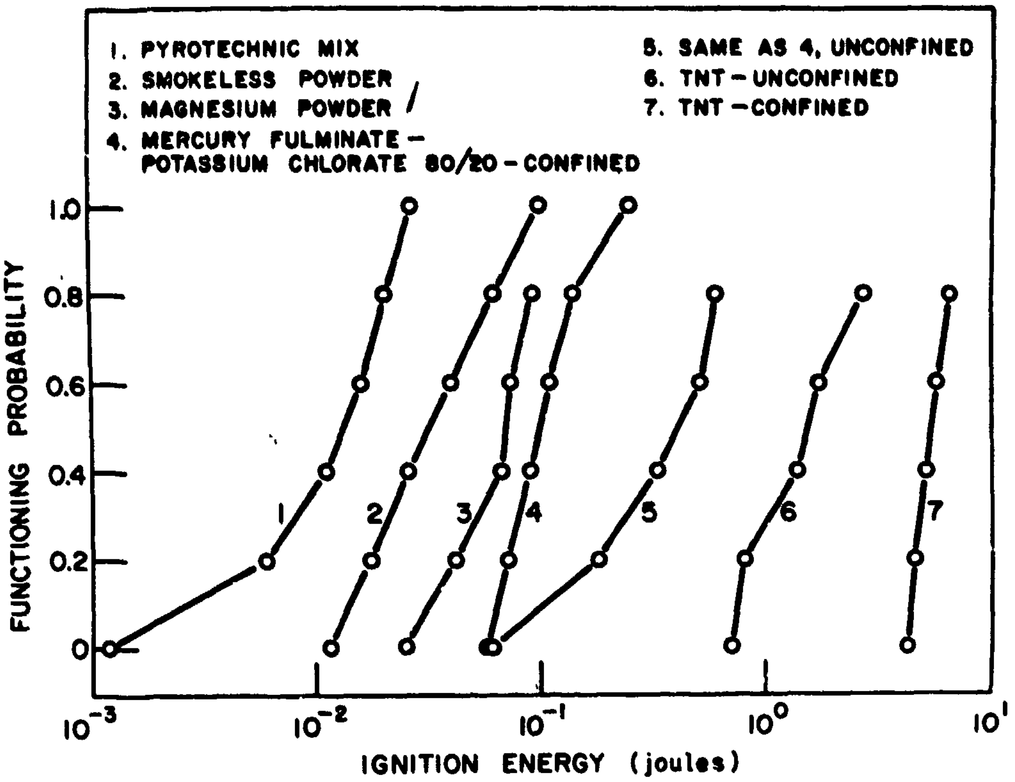


Fig. 3 - Energy Required for Given Functioning Probability of Common Explosive Materials

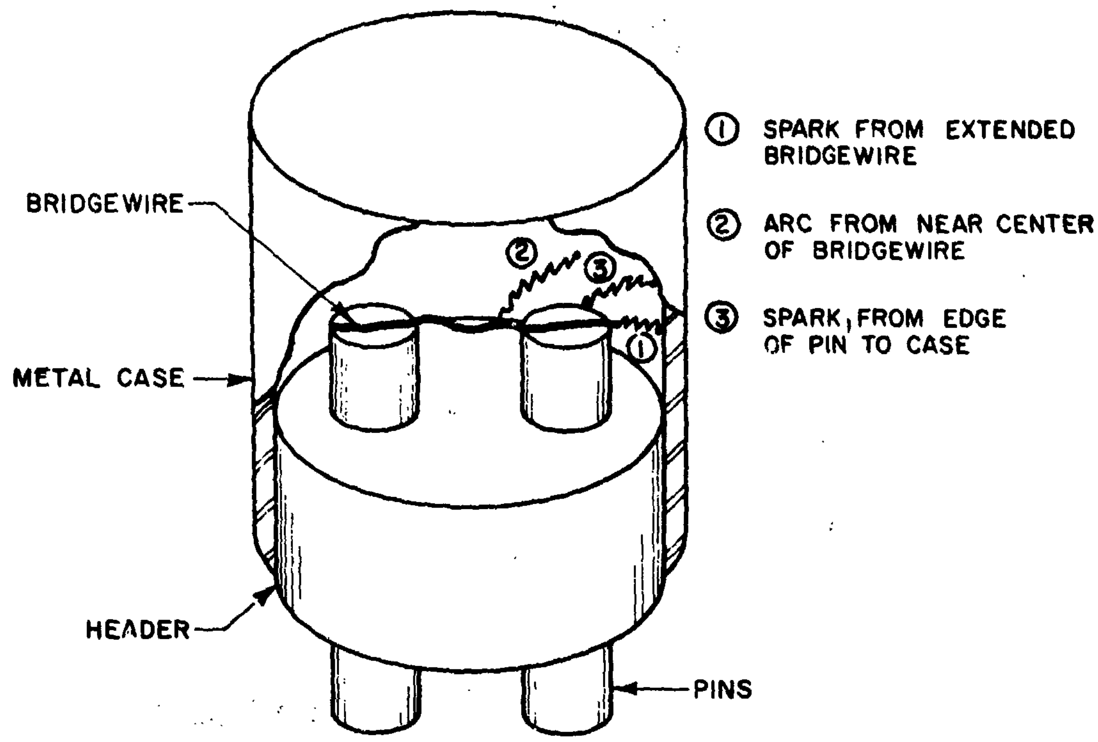


Fig. 2 - Firing Modes of Typical Electroexplosive Devices

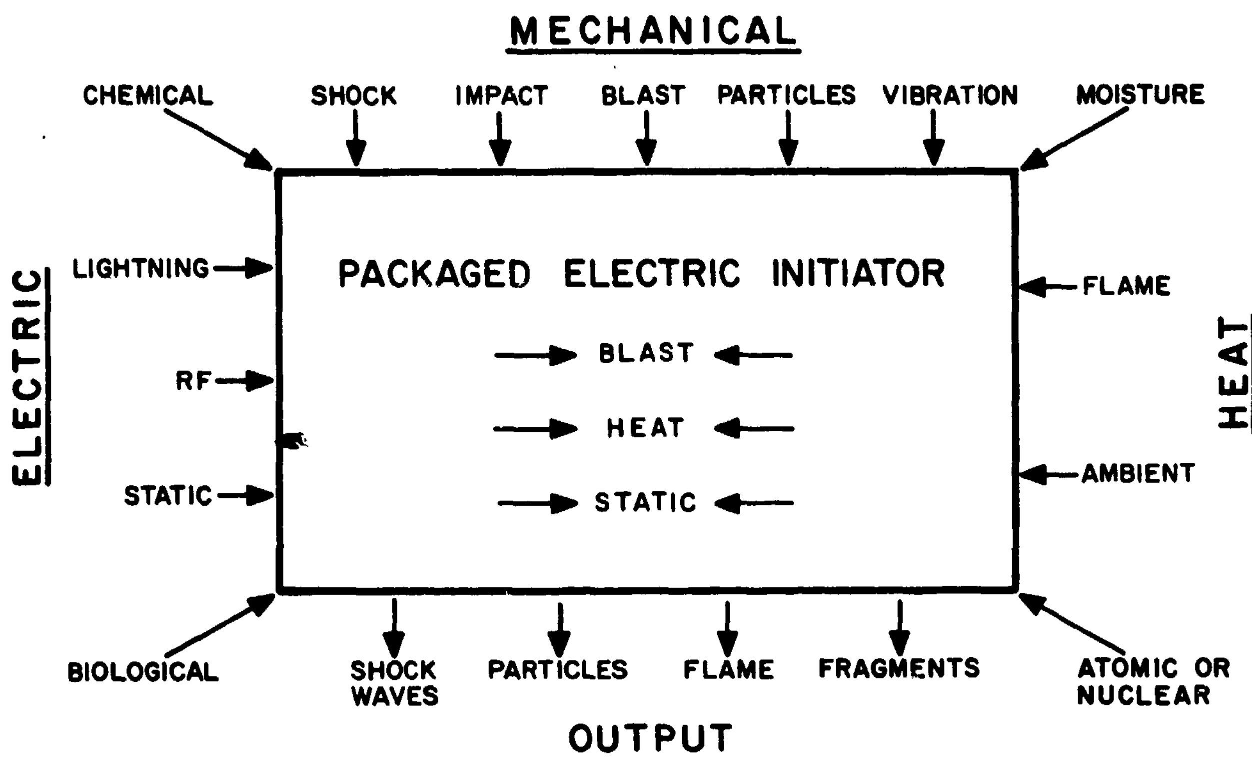


Fig. 1 - Some of the Factors to be Considered in Initiator Packaging

Lightning Parameters Related to the Initiation of Electroexplosive Devices

by Marx Brook *

1. Introduction

This report is concerned with the measurement of lightning stroke parameters as they relate to the accidental detonation of electro-explosive devices. In what follows we shall discuss the results of measurements made in the summer of 1966 in cooperation with the Safety Engineering Group of the Sandia Corporation. The important factors influencing the initiation of this study were:

1) The research work being carried on at the Langmuir Laboratory of New Mexico Institute of Mining and Technology on the fine structure of lightning,

2) The interest of the Safety Engineering Group at Sandia in defining and obtaining quantitative parameters and values for safe and unsafe operations during situations of disturbed weather,

3) The interest of the Mining Engineering Department at NMIMT in obtaining information which might be applicable to defining safety standards in mining operations.

The studies were initiated in a very preliminary way late in the summer of 1965; in the summer of 1966, the data presented here were obtained.

2. The Lightning Discharge

No attempt will be made here to review all of the characteristics of lightning which may be of interest. We shall provide only a brief review. For a more thorough treatment, the reader is referred to the article by Schenland (1957).

Lightning flashes are divisible into two major categories: intra-cloud flashes and cloud-to-ground flashes. Air discharges (i.e., streamers which originate inside the cloud and terminate in the air around or below the cloud but do not reach the ground) are grouped with the intracloud discharges.

The average duration of the total electrical activity associated with a lightning flash (or discharge) is approximately 1/2 second. This value is applicable to both intracloud and cloud-to-ground flashes, and can be verified readily by recording the electric field changes or by measuring the duration of the light pulse output.

*Presented by L. M. Jercinovic

The lightning discharge consists of a large number of electric field changes (or pulses) and may be divided into various types, depending upon the amplitude and frequency spectrum associated with the pulses. In general, the pulses give rise to radiation which covers the electromagnetic spectrum from a few Hz to greater than 10,000 MHz.

The electric fields at the surface before and after lightning discharges may be positive or negative with values from zero to 6000 V/cm.

The frequency characteristics of the emitted radiation from cloud discharges differ from the cloud-to-ground discharge in primarily one aspect--the cloud-to-ground discharge involves a rapid return-stroke which produces the largest single electric field-change of any of the fine-structure elements. A return-stroke is always preceded by a downward moving negative streamer or leader which, for the first stroke of a flash, is called a stepped leader. The stepped leader moves through initially non-ionized air in a tortuous path toward ground. It shows many kinks and branches as it progresses downward in an almost random-walk-like fashion. The various branches which form are essentially similar, and usually continue on toward earth independently. The first branch to get within about 100 meters of the earth completes the path to ground--positive streamers from a wide area under it rise from the earth to join the negative stepped leader.

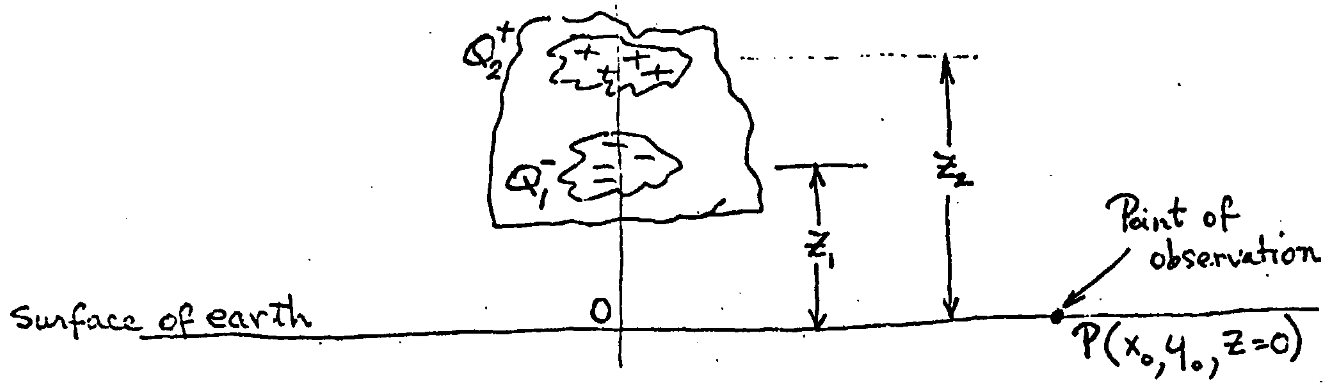
The return stroke now moves up the channel as a space potential wave with a velocity of about 1/2 the velocity of light and with an average peak current of about 20,000 amperes. The current rises to 90% of final value in from 2 to 7 μsec, and falls to one-half value in about 40 μsec. The current in the return-stroke is essentially zero after 100 microseconds, although currents of the order of 150 amperes have been found to persist for as long as 0.4 second (long, continuing currents). About one out of every 6 return strokes may be expected to end in a long-continuing current of average value 175 amperes for an average duration of 150 msec.

After the first return stroke, cloud activity ensues for a period of about 40 msec, at which time a dart leader emerges from the cloud, refreshing the ionization in the old channel. The dart leader is followed by a second return-stroke, and the sequence, leader--return-stroke, <u>may</u> continue for as many as 26 times (greatest number of return strokes in a single flash measured in New Mexico). On the average, there will be from three to five return strokes per flash and the time between them will be about 40 milliseconds.

The charge brought to earth by lightning is almost always negative, although strokes to towers have been cited in which positive charge was involved. Normally, each lightning stroke involves from 2.5 to 5 coulombs of negative charge. Long-continuing currents, however, may involve ten times as many coulombs. Thus, a lightning flash containing four or five return strokes involves from 20 to 30 coulombs of charge.

It is not as straightforward to describe the number of coulombs involved in a cloud flash or air discharge. A better parameter is perhaps the electric dipole moment destroyed by the discharge. The dipole moment

is an excellent parameter for describing both cloud-to-ground and intra-cloud flashes.



First, we treat a flash to ground. In this case, we involve only the negative charge Q_1^- in the cloud. The electric field at $P(x_o, y_o)$ due to the charge Q_1^- and its image in the earth Q_1^+ is

$$E = \frac{1}{4\pi\epsilon_0} \frac{(-)2Q_1Z_1}{(x_0^2 + y_0^2 + z_1^2)^{3/2}}$$

E in volts/M, x,y,Z in meters, Q in coul.

If all of Q_1^- is destroyed in the lightning stroke, E then becomes ΔE, the total field change, and we have

$$\Delta E = \frac{1}{4\pi\epsilon_0} \frac{2Q_1Z_1}{(x_0^2 + y_0^2 + z_1^2)^{3/2}}$$

Note that the term $2Q_1Z_1$ is the electric dipole moment of Q_1^- and its image Q_1^+ is destroyed in the stroke. The term $(x_0^2 + y_0^2 + Z_1^2)^{3/2}$ is the cube of the slant range from the measuring station at P to the approximate center of the charge. Thus we may write

$$\Delta E = \frac{1}{4\pi\epsilon_0} \frac{M}{R^3}$$

where M = dipole moment and R is slant range. If $R >> Z$, then the horizontal distance is approximately equal to R, and the two may be used interchangeably.

This relationship $\Delta E = \frac{1}{4\pi\epsilon_o}\frac{M}{R^3}$ provides us with an approximate method for estimating the distance to a vertical stroke to ground. On the average, the value of M lies between about 120 and 180 coulombs/kilometers. We take 150 coul/km in this work. Then a measurement of ΔE is sufficient to provide an estimate for R:

$$R^3 = \frac{1.35\times10^6}{\Delta E} \text{ Km}, \qquad \text{for } \Delta E \text{ in V/M.}$$

Where distances to the stroke channels were not measured, they were calculated by the above approximation. If the horizontal distance to the stroke channel is less than about 10 km, R must be used as the slant range. In New Mexico thunderstorms, Z_1 is usually between 17,000 and 25,000 ft MSL, or about 6 km MSL. At Socorro (El 4600 MSL), Z_1 was measured to be about 2.8 km for the first stroke and as high as 10 km for the last stroke in multiple stroke flashes.

In the case of multiple-stroke flashes to ground, the negative charge shown in Figure 1 may be approximated by a number of small spherical charges spaced about 300 meters above one another, each sphere containing the charge q_1 brought to earth by the individual strokes. Thus the relationship

$$\Delta E_i = \frac{1}{4\pi\epsilon_o}\frac{M_i}{R_i^3}$$

may be applied to the individual strokes in a flash, where ΔE_i is the measured field change for an individual stroke.

In the case of a cloud flash, we assume that both Q_1^- and Q_2^+ shown in Figure 1 are destroyed in the discharge. Then we have

$$\Delta E = \frac{1}{4\pi\epsilon_o}\left(-\frac{2Q_1Z_1}{(x_0^2 + y_0^2 + Z_1^2)^{3/2}} + \frac{2Q_2Z_2}{(x_0^2 + y_0^2 + Z_2^2)^{3/2}}\right)$$

Again, if the flash is distant $(x_0^2 + y_0^2 >> Z_1^2$ and $Z_2^2)$ we may write R for the horizontal distance and get

$$\Delta E = \frac{1}{4\pi\epsilon_o}\frac{2Q_1\,(Z_2 - Z_1)}{R^3} \qquad \text{where } Q_1 = Q_2$$

which may also be written as

$$\Delta E = \frac{M}{R^3}$$

As the thunderstorm electric field builds up, the electric field at the surface becomes high enough to produce point discharge. The threshold field for the onset of point discharge (or corona) currents depends upon geometrical factors; a value of 10 volts/cm is generally accepted as sufficient to produce point discharges over reasonably flat terrain. Trees, grass, leaves, brush, etc, provide a multitude of points which go into point discharge in high fields.

The magnitude of the point discharge current is a complicated function of point geometry, electric field, and wind velocity. Generally, currents are found to be in the range of microamperes.

Corona or point discharge currents may also occur in fair weather fields if conductors are elevated to sufficient height. The earth's fair weather field is normally of the order of 1 volt/cm; thus a grounded, sharp, needle point elevated to a height of several meters will emit corona.

Induced voltages due to close lightning discharges are perhaps the greatest potential contributors to accidental detonation. Quantitative values for the induced voltage in specific Conductor geometries can be calculated if the following four quantities are known:

1) the lightning current variation as a function of z, the height, and the time t;

2) the inclination (or better, the exact geometry) of the lightning channel;

3) the resistivity of the earth;

4) the geometry of the conductor under study.

An inspection of the four quantities listed above will reveal that, generally, only one or two of the quantities are known; it is usually not possible to measure all four quantities simultaneously.

The most important lightning parameter affecting the magnitude of the induced voltage in a conductor is the rate of rise of current, $\frac{dI}{dt}$. The quantity dI/dt can be measured approximately by setting out a loop of known area and adequate frequency response. From

$$\mathcal{E} = -\frac{dB}{dt} \cdot A ,$$

$\mathcal{E}$ = induced EMF, A = area of loop, B = Magnetic induction due to the lightning source. We can attempt to relate the measured $\mathcal{E}$ to $\frac{dI}{dt}$. As a very rough approximation, consider the lightning channel as a vertical conductor of infinite extent, and that the current-time variation along the channel is negligible. This is the quasi-static approach, through which we can relate B to I very simply:

$$B = \frac{\mu_o I}{2\pi R} \quad \text{where R is the distance from the discharge;}$$

then $\frac{dB}{dt} = \frac{\mu_o}{2\pi R}\frac{dI}{dt}$ so that $\mathcal{E} = -\frac{\mu_o}{2\pi R}\cdot\frac{dI}{dt}$ volts.

If we take the maximum rate of change of current as 10,000 amperes/microsecond, we get, in this approximation, at R = 100 meters,

$\mathcal{E}$ = 20 volts in a loop of unit area oriented in the most favorable direction.

The quasi-static approximation is obviously not a good one, since the wave-length of the radiation at frequency of 10^6HZ is only 300 M. We shall not attempt to do the more rigorous calculation, since our loop data of last summer were unfortunately recorded on a defective channel.

3. Instruments Used to Measure Lightning Parameters

1. Field measurements were made using an NMIMT field mill. The circuit for the field mill is shown in Figure 2. Sensitivities from 300 volts/M to 30,000V/M are selected by a front panel switch.

2. Field Changes. Two instruments were used to record field changes:

a) Slow antenna - this is a high input impedance instrument with a time constant of approximately 10 seconds. The long time constant allows one to follow the field variations faithfully over the period of a flash (~0.5 second), but the output returns to zero level between flashes (1 every 20 seconds or so). The circuit is shown in Figure 3.

b) Fast Antenna - this instrument has a very short time constant (~100μsec) and emphasizes the most rapidly changing events in the flash. The circuit is given in Figure 4.

3. Rate of rise of current. Loop antenna. The antenna was made in the form of a square loop of 0.003-inch copper wire, 1 meter on edge, which

was supported inside an aluminum tube 3 x 3 inches square inside cross section, and split on the top 1 meter side to minimize induced currents. The resonant frequency of the loop was measured to be about 60 mc; the loop was terminated in a damping resistor, which also was used as a load resistor.

The output of the slow antenna was recorded on an Ampex FR-1300 tape machine, along with thunder records from a B & K ½-inch capacitor microphone, and the IRIG B time code. The output of the fast antenna was recorded on two channels of an FR-1400 tape recorder; the first channel direct record with 1.5 MHz response; the second channel F-M with 0-400 kc response.

The video output from 60, 150 and 420 MHz receivers were also recorded on the FR-1400 machine. In addition, the outputs from two optical sensors, one at H-α (6563Å) and the other N_2^+, (3914Å), were measured along with the electric field change meter and receiver outputs.

4. Data

1966 Data on Lightning Flashes Which Produced Detonations

Table 1 lists the date, time, and the instruments which recorded lightning data for six events which detonated a total of 21 devices.

Table 1.

Day of Year	Date	Time	No. of devices Detonated	Remarks
210	7-26-66	17:32:33	one	No lightning data other than Electric Field Mill
216(A)	8-4-66	12:27:57	eight	Field Mill, Ampex FR-1300 recorder showing slow antenna
216(B)	8-4-66	12:35:26	two	on two sensitivities, microphone for time to thunder.
220	8-8-66	14:20:42	eight	Honeywell galvanometric recorder of Field Mill, Slow
221	8-9-66	14:22:40	one	Antenna, Rain Intensity and Time Code*
238	8-26-66	14:10:34	one	

*Time code on day 221 too faint due to accident in processing.

In addition to the data in Table 1, a number of electric field changes (large) were analyzed in order to compare field changes which caused detonations with those which didn't. Table 2 is a complete list of the storms analyzed.

Table 2. Listing of All Flashes Analyzed

Day of Year	Date	Ampex FR-1300	Honeywell Recorder	Distance	Number of Detonations
210	7-29-66	-	-		1
216(A)	8-4-66	X	-	Within 1 Km	8
216(B)	8-4-66	X	-	Within 2.2 Km	2
219	8-7-66	-	X		-
220	8-8-66	-	X	Within 2 Km	8
221	8-9-66	-	X		1
222	8-10-66	-	X		-
223	8-11-66	-	X	15-25 Km	-
224	8-12-66	X	X	15-25 Km	-
226	8-14-66	-	X		-
227	8-15-66	X	X	3.5-8 Km	-
228	8-16-66	-	X	~ 8 Km	-
229	8-17-66	-	X	~ 3.2 Km	-
238	8-26-66	-	X		1
239	8-27-66	X	X	20-25 Km	-

On the following days, data were not suitable for analysis:

Day 210 (7-29-66) 17:23:33, no data

Day 221 (8-9-66) 14:22:40, Honeywell data but time code too faint.

Day 238 (8-26-66) 14:10:34, Honeywell data but slow antenna off scale during stroke and Electric Field Meter A. C. power blown during stroke.

INITIATING STROKES

Day 216(A) 8-4-66 #10 12:27:57

No Honeywell Record

Slow Antenna Range: 10^9, x.2 and x1

Slow Antenna Deflections: (on x1 range)

Stroke #

(1)	> div	=	>156,000 V/m (off scale)
(2)	10.8 div	=	46,000 V/m
(3)	2.1 div	=	8,900 V/m
(4)	2.0 div	=	8,500 V/m
(5)	2.5 div	=	10,500 V/m
(6)	1.1 div	=	4,600 V/m
(7)	1.8 div	=	7,600 V/m
			242,000 V/m

Calculated distance: R = 1.8 Km.

Day 216(B) 8-4-66 #31 12:35:26

No Honeywell Record

Slow Antenna Range: 10^9, x.2 and x1

Slow Antenna Deflections: (on x1 range)

Stroke #

(1)	45 div	=	190,000 V/m
(2)	3.5 div	=	14,800 V/m
			205,000 V/m

Calculated distance: R = 1.9 Km.

Day 220 8-8-66 14:20:42

Electric Field Mill Range: 10K

Slow Antenna Range: 10^9

Electric Field Mill Deflection: 2-7/16" (bad data because power for EFM blows during the stroke)

Slow Antenna Deflection: -11" (estimate - off scale)

$$\Delta E = -110 \text{ div} \times 880 \frac{V/m}{div}$$

$$\Delta E = -97{,}000 \text{ V/m}$$

negative field change

Calculated distance: R = 2.4 Km

Large Non-Initiating Strokes

Day 216 (8-4-66)

Time	Electric Field
12:33:13	30,400 V/m
12:34:03	33,400 V/m
12:34:57	26,600 V/m

Day 219 (8-7-66)

11:43:30	9,000 V/m
11:48:40	11,000 V/m
11:58:00	9,500 V/m

Day 220 (8-8-66)

Time Code off	16,000 V/m
(Power blew during	15,000 V/m
14:20:42 stroke)	56,000 V/m

D

Day 221 (8-9-66)

Time Code Generator still out.	17,000 V/m
	13,000 V/m
	14,000 V/m

Day 222 (8-10-66)

13:53:45	400 V/m

Day 223 (8-11-66)

13:43:30	5,000 V/m
15:52:45	4,200 V/m
16:04:15	6,000 V/m

Day 224 (8-12-66)

14:30:20	4,200 V/m
14:42:40	5,000 V/m
14:52:10	7,000 V/m

Day 227 (8-15-66)

16:51:58	3,500 V/m
17:05:24	3,800 V/m
17:12:41	3,800 V/m

Day 228 (8-16-66)

10:50:30	5,800 V/m
10:52:30	6,500 V/m

Day 229 (8-17-66)

11:41:00	4,200 V/m
11:44:00	3,500 V/m
13:04:00	9,000 V/m

Dey 238 (8-26-66)

14:20:25	38,000 V/m
14:23:20	35,000 V/m
14:26:50	38,000 V/m

Day 239 (8-27-66)

12:35:00	7,200 V/m
12:36:05	6,900 V/m
12:43:36	8,100 V/m

5. Conclusions

Tabulated below is a summary of the measurements for flashes which caused detonations and for flashes which did not.

Initiating Discharges:

Devices blown	Elec. Field 1st Stroke	Change (V/m) Sum of all strokes
8	>156,000	> 242,000 1st stroke off scale
2	190,000	205,000
8	> 97,000	(Power blown)

Largest Non-Initiating Discharges:

56,000 V/m
38,000 V/m
38,000 V/m
35,000 V/m
33,000 V/m
30,000 V/m

From the above data, it appears that the threshold for detonation, based upon the electric field-change values, lies somewhere between 60,000 V/m and 100,000 V/m. Using these values to compute the approximate distance from the strokes, we get something like 2.4 to 3.0 kilometers as the distance beyond which the average lightning flash will not produce detonation of the caps and antenna configurations tested.

This conclusion must be regarded as extremely tentative and, certainly, not absolute. We have based the distance values obtained on an average value for the dipole moment destroyed in a flash, using the value of 150 coul-km. The use of an average value here is certainly not desirable. One would like to collect enough statistics to be able to state a distance such that strokes occurring beyond that range would not cause detonation with (say) 95% certainty. Obviously, the data here are not suitable to this purpose.

6. Recommendations

On the basis of this one summer's sample, the results are encouraging. Surprisingly, it does appear that one can bracket the value of the threshold electric field change which produces detonation in (say) 95% of the cases if enough statistics are available.

In addition, if more work along these lines is contemplated, we would recommend the use of a pair of crossed loops to measure the rate-of-rise of current. Along with electric field change and

$$\frac{dI}{dt}$$

measurements, some effort should also be made to determine the distance to the flash more accurately. Perhaps a stereo camera pair with hydrogen-α filters would work in daylight as well as at night.

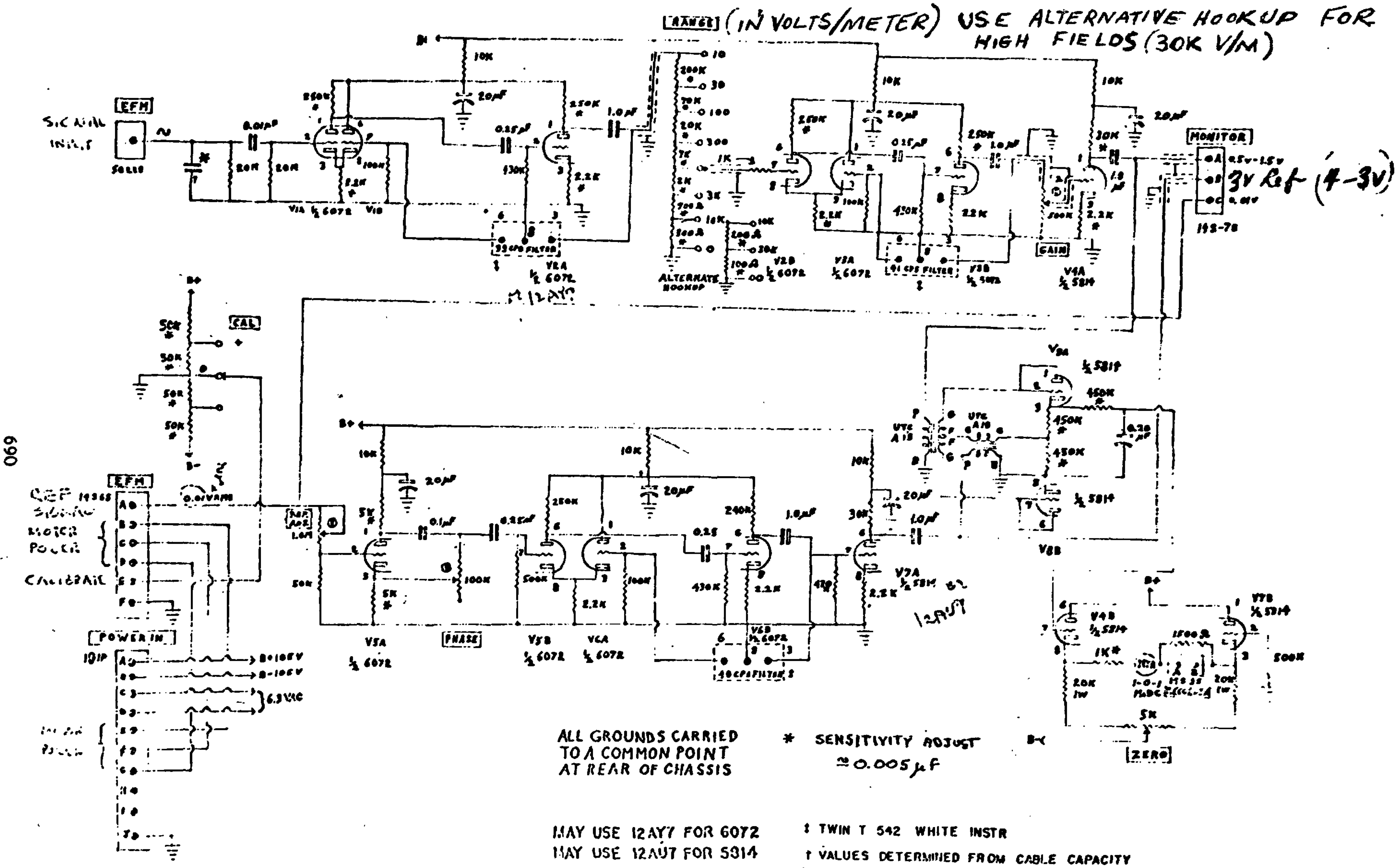
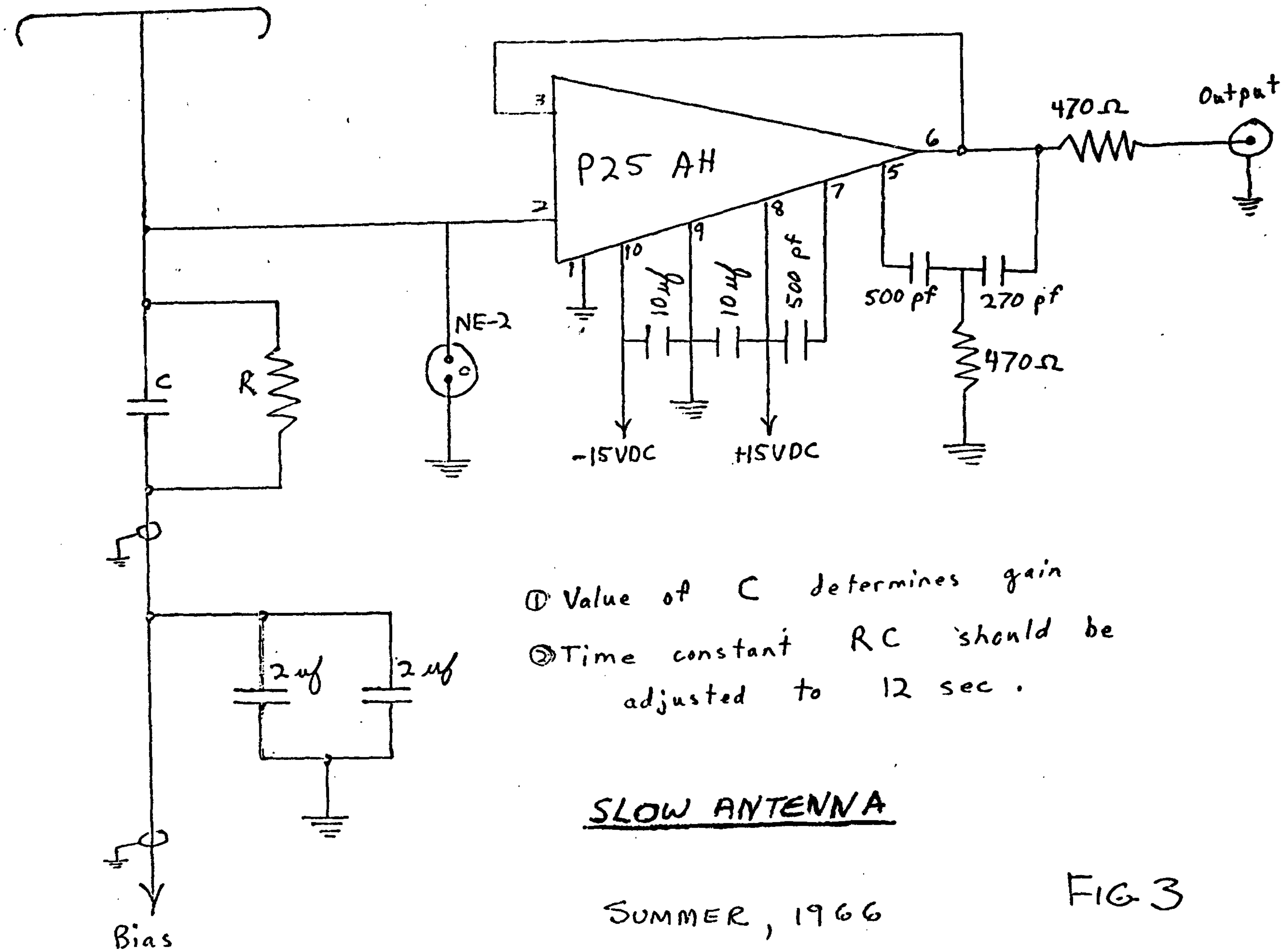


FIG 2

ELECTRIC FIELD METER AMPLIFIER



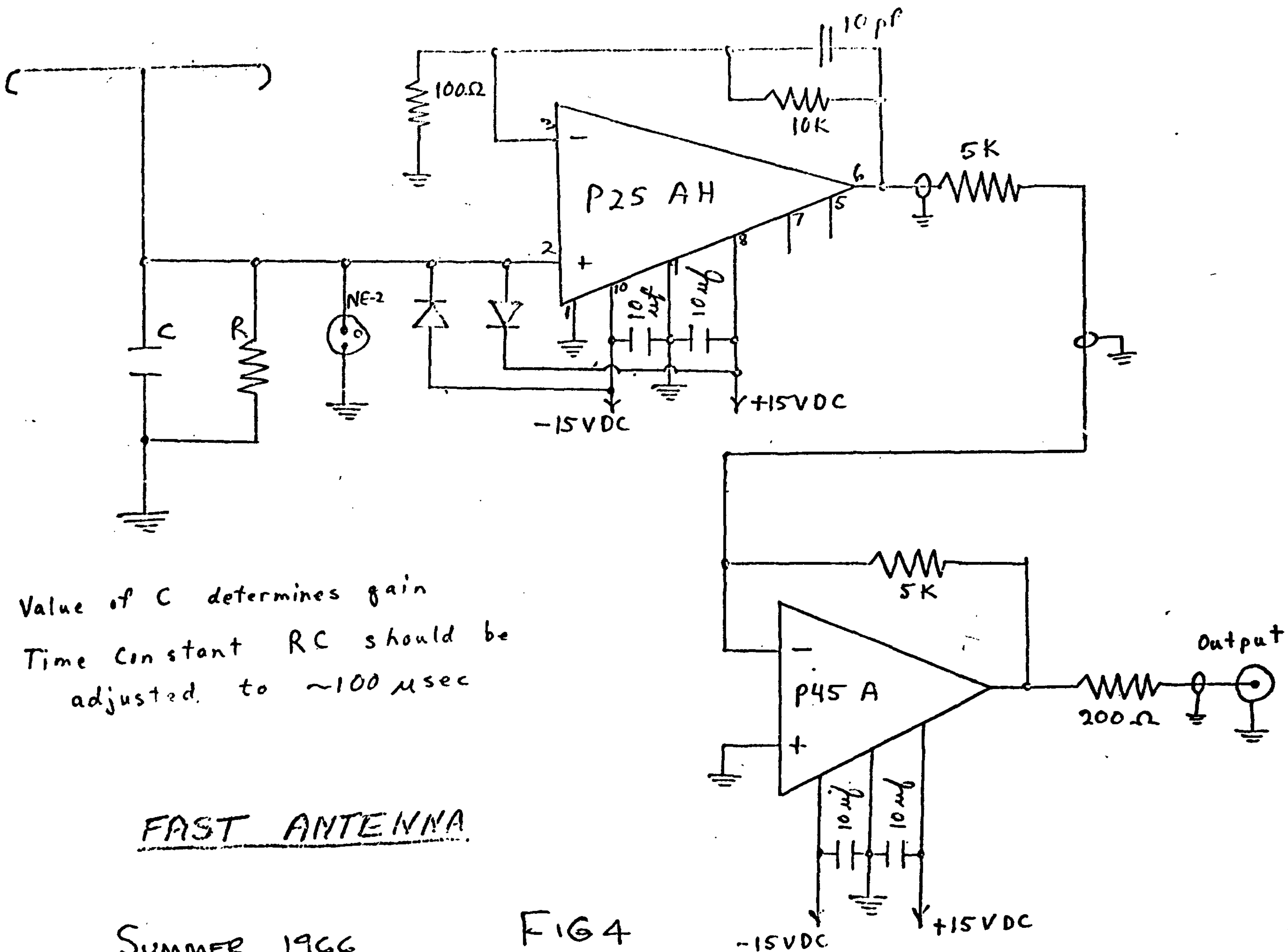
① Value of C determines gain

② Time constant RC should be adjusted to 12 sec.

SLOW ANTENNA

SUMMER, 1966

FIG 3



① Value of C determines gain
② Time Constant RC should be adjusted to ~100 μsec

FAST ANTENNA

SUMMER, 1966

FIG 4

ONE-HALF DAY SPECIALIST SESSION

"DEFENSE CONTRACT ADMINISTRATION SERVICES/EXPLOSIVE SAFETY PROBLEMS"

Session Chairman:

Major Tommy Box, USAF

Chief, Office of Specialized Safety & Flight Operations

DCASR, Philadelphia

Panel:

Mr. F. M. Bishoff, Army Materiel Command, Washington, D. C.

Mr. R. H. Kieke, Armed Services Explosives Safety Board

Mr. P. H. Schuyler, Hq USAF, Norton AFB, Calif.

Mr. E. W. VanPatten, Army Munitions Command, Dover, N.J.

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INTRODUCTION

It is my pleasure to act as Chairman of the DCAS Panel, assembled here this afternoon in the unavoidable absence of LtCol Lowell E. Ward, USAF, Chief, Specialized Safety & Flight Operations, DCAS. We are fortunate also to act as host to our panel guests, Mr. Bishoff, Army Materiel Command; Mr. VanPatten, Army Munitions Command, Mr. Schuyler, Norton AFB, Mr. Kieke, ASESB; and our Coordinator, Mr. Knasel, ASESB.

The official delegation for the administration of the safety aspects of Defense contracts was finalized January 1967. This delegation was heralded by first, a letter from each of the DCAS Regions stating that they had attained their readiness posture and second, by notification to the military services of the Regions' preparedness.

What was accomplished by this move? The addition of the safety responsibility to Contract Administration was the final link to complete the chain. Under the original charter, the DCASRs were given responsibility for all aspects of contract administration except safety as a service to military procuring activities.

As you know, procurement actions are initiated by the buying military services who have the option, once the contract is let, of availing themselves to the administrative services offered by the DCASRs for retaining administrative control over the contracts.

As you can see, prior to January this year, the military services had been responsible for the administration of safety on contracts which had otherwise been delegated to one of the DCASRs for administration of all other contractual elements.

The justification for including safety under the DCASRs is self-evident if one supports the concept of the DoD's intent to present "one-face-to-industry."

I hope the implication is clear that the DCASRs' safety responsibility encompasses not only you gentlemen, the representatives of the explosive industry, but all industries performing on Defense contracts.

Recognizing the scope, the eleven DCASRs have been permitted a certain flexibility to develop an individual safety program to best suit their regional needs due to the geographical concentration and/or diversification of types of industry.

Headquarters DCAS, while determining policy, has also maintained management control through field visits and, most productively, through quarterly meetings of the Chiefs and Deputies of the Safety Offices representing the individual regions. Through these meetings, a review and correlation of the individual DCASR's progress and development of its safety program have been discussed, and a team atmosphere has prevailed.

Much progress has been made. Much work remains to be done. Yet, the ultimate goal is to support, within the constraints of industrial diversification, the stated policy of "one-face-to-industry."

SUMMARY OF PROBLEMS & DISCUSSIONS

Problem

One of the major problem areas encountered by the DCASRs in the administration of explosive safety is the small contractor.

Discussion

It is recognized that the small business contractor is an important element in support of the overall Defense effort; that the small businessman is an important factor in the American economy, as the employer of a significant segment of the skilled and unskilled work force.

For this reason, the small business administration, established by and operating under federal legislation for the purpose of rendering financial and technical assistance to small business, furnishes guidance to procuring activities in assigning small business set-asides to selected Defense contracts. In recognizing the intent of the small business law - to assure equity in competition for Defense contracts and to assure utilization of the potential of this vital resource - one must not distort the performance capabilities of the small contractor as is frequently the case.

Probably, we all agree that the value of the small contractor is to fill the void in the "small dollar" contract area, and in subcontracting for parts or components within his capability to produce. These activities are important to the Defense effort, and provide a real saving to the prime contractors. If we agree with this premise, then we may question the reasonableness of soliciting bids from the small businessman for contracts beyond his capabilities. Experience has shown that many small contractors are involved in explosive operations where they lack the facilities, the tooling, the capital, and, in some cases, the labor skills and technical competence to perform on some contracts.

How does this happen? In many instances, the small contractor lacks the ability to properly evaluate the contents or the impact of the reqquirements contained in the IFB.

One of the DCASRs' responsibilities is to perform pre-award surveys in the safety area. With proper discharge of these responsibilities, some of the current problems of administering contracts awarded to small concerns - of which it might be said "should not be in business" - can be minimized. However, the effectiveness of proper pre-award evaluation of the small businessman is not the total solution. This is a multi-faced problem requiring education and understanding of the Procuring Contracting Officers and Small Business Offices of procurement activities, and adequate

and reasonable regulatory instructions from the DoD. The latter requirement will be partially fulfilled by the publication and inclusion in the Armed Services Procurement Regulations, of the DoD Explosives Safety Manual currently being developed.

Problem

Where is the equity between the middle-sized contractor who has a significant capital investment in facilities, equipment, and technical skills and the small operator who has only the minimum requirements and certainly not the overhead investment?

Discussion

There is no concise answer to this problem. However, the intent of the DoD's concept of "one-face-to-industry" is an effort to reconcile the problem. For example, the fact that DCAS now has the responsibility to perform pre-award surveys in all the functional areas tends to assure consistency in evaluating competitive contractors regardless of size.

Problem

When is the DCAS Safety Manual coming out?

Discussion

The manual is not a DCAS manual. It is a DoD manual which is currently being reviewed by the Office of the Assistant Secretary of Defense. Representatives of the military services and the ASESB have assisted in compiling the current draft. The manual has been circulated through the Military Departments, ASESB, and representatives of civilian explosive industry for comment.

Problem

How will the DoD Safety Manual apply to contractors and will it also apply to military facilities?

Discussion

Some facilities of the individual services will undoubtedly be exempt from the provisions of the DoD Safety Manual. It is designed, primarily, to provide instructions for Defense contractors. The impact on procurement agencies will have to be reviewed by the DoD Legal Office for its "boilerplate" applicability to contractor-owned, contractor-operated facilities.

Problem

What about plants having some Defense contracts with waivers and some contracts without waivers on safety requirements?

Discussion

Only the safety provisions of the individual contract may be enforced. Therefore, if a mix of contracts lend themselves to the segregation of operations within a contractor's facility, there would appear to be no conflict between contracts having enforceable safety clauses and contracts having waivers. If within the contractor's facility there are operating areas utilized for joint operations on conflicting contracts, the safety provisions of the enforceable contract would take precedence and negate that portion of the contract containing a waiver.

Problem

What is the "legal language of the contract?"

Discussion

As it pertains to safety, it is limited to those clauses that are enforceable. At the present time, many of the safety clauses in the DoD contracts are advisory in nature and for the guidance of contractors. It is the contractor's responsibility to establish and enforce a safety program that provides safety to his personnel and facilities and enhances the ability to meet production schedules as required by the contract. This management responsibility is implicit, much the same as the responsibility that the contractor maintains accounts, plans production, or meets payroll schedules for his employees.

Problem

Is there a distinction between Systems Safety and Explosive & Industrial Safety?

Discussion

Yes. The requirement for Systems Safety is written into the terms of the contract. This requires that the Contracting Officer will be provided with the information contained in the Systems Safety Plan, and, as the name implies, applies to a specific end-item or weapons system.

Problem

How can private industry help in the administration of safety?

Discussion

By establishing and administering their own internal safety program. Defense contracts are based on Defense needs. The DoD is buying the contractor's production capability and his ability to manage the quality, quantity, and the safety required to produce the item being procured. Neither the Government nor the contractor possesses all the explosive

safety knowledge. Some of this knowledge is gained during the development and/or production phase of the contract. In purely production contracts, the contractor's responsibility to maintain and enforce his safety program assures that contractual requirements are met. It assures delivery of a quality product, in the quantity required, in a timely manner, and maintains safety conditions for Government personnel and property and a safe working environment for contractor personnel. This is a part of the purchased management function. Further, unfavorable publicity resulting from accidents can reflect on either the contractor or the Government or both, and will be minimized by good accident prevention practices.

CONCLUSION

In the light of the foregoing discussions, it is evident that there is the necessity for maximum cooperation between Government representatives and private contractors in the administration and performance of Defense contracts in the explosive safety area. As the DCASRs strive to improve their individual responsibility in the administration of Defense contracts, it becomes more apparent that quality, production, and safety are indivisible. This fact points out that the Defense contractor is an integral part of the DoD team. Team effort demands mutual assistance, cooperation, and support in accomplishing safety objectives, explicit or implied in the explosive safety field. The DoD, with you a member of the team, can better discharge its obligations and responsibilities in the Defense effort of the United States.

ONE-HALF DAY SPECIALIST SESSION

"RESEARCH & DEVELOPMENT"

Session Chairman:

Dr. C. B. Dale

Naval Ordnance Station

Indian Head, Md.

Papers Presented Were By:

Dale, McDevitt, Zimmer, Goldberg, Hudson, & Robb, NOS Indian Head, Md.

D. H. Jones, Naval Weapons Lab, Dahlgren, Va.

Dr. H. Leeming, Lockheed Propulsion Co., Redlands, Calif.

T. P. Liddiard, Naval Ordnance Lab, Silver Spring, Md.

R. W. Woolfolk & A. B. Amster, Stanford Research Institute, Menlo Park, Cal.

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STATUS REPORT ON HAZARD EVALUATION OF LARGE SOLID ROCKET MOTORS

C. Dale, Joyce McDevitt, M. F. Zimmer,
M. Goldberg, M. Hudson, R. Robb
Naval Ordnance Station, Indian Head, Maryland

INTRODUCTION

Since a reliable measure of the large motor safety cannot await the lengthy accumulation of operational experience, and considering the size and cost of the solid motor systems being developed a logical investigation approach has been undertaken to determine the potential hazards and to describe the "prior-to-the-fact" safety during all aspects of use of the large motor. For a realistic appraisal of the damage potential, this approach to the hazard analysis must include:

(a) possible incidents or malfunctions and their contributing stimuli

(b) effects of the resulting stimuli on the motor

(c) damage to the surroundings resulting from possible reactions of the solid motor.

The results of a preliminary investigation based on the current state-of-the art will be presented as a qualitative indication of the hazards which may result.

Dependent environmental parameters and parameters associated with the motor propellant and configuration are important factors that must be defined. To best accomplish such an analysis considering the various events and dependent factors, a systems approach has been proposed.

By applying a systems concept to the hazard evaluation of large motors through the hazard tree technique, a thorough analysis has been achieved. By subdividing the motors' life

into operations such as handling, transportation, storage, checkout and assembly, launch preparation and flight, the potential accidents can be easily analyzed. The hazard tree, developed by modifying the well recognized fault tree technique for component failures-mode-and-effect analysis considers manmachine and environmental interfaces as well as hardware oriented failures in its analysis of potential accidents. The scope of the hazard tree is also vast in comparison with that of its predecessor in that is does not stop with the occurence of accidents or failutes but proceeds on to designate the degree of damage possible to the motor and to the surroundings. This analysis technique provides a tool most desirable to a system safety analysis. In its present form, the hazard tree provides a communications aid to more effectively describe the potential hazard of large motors.

While extensive information concerning past accident experience with other missiles, propellants, and explosives, and theoretical aspects of initiation, explosion, and detonation of composite propellants have been utilized to develop the individual hazard trees; the state-of-the-art allows only a qualitative estimate of safety. From conception through operational readiness, there is a continuing need for formulating, collecting, and analysing pertinent information for evaluating the hazards of large solid motors. The flexible nature of the hazard tree premits the informa-

tion obtained to be input into the analysis so that more accurate results may be obtained for each accident analyzed.

The initial task, the assignment of relative probability estimates for the accidents' occurrence, will allow the most probable and hazardous accidents to be identified and the causes of these accidents to be investigated further. A survey of expert opinion in all applicable areas of safety, human factors, logistic modes, etc., is planned for the immediate future as a basis for estimating these relative accident probabilities. These data will be analysed with care according to the experience and background of each expert surveyed. While it is unlikely that two peopel would assign the same absolute probability of occurence, a survey designed to obtain comparative values with consistency maintained through cross-checking can provide valid relative results. This relative probability data can then be included in the hazard tree analysis by applying methods analogous to reliability analysis and analyzed with the aid of Boolean Algebra. Whereas reliability analysis requires rather exact estimates of the probability with which a system can function as intended, safety is not assured. Components of a system that are highly reliable are not necessarily safe. The whole system must be safe. In conducting a system safety analysis, quantitative estimates of accident potential, though obtained by approximations, can be profitably employed for predicting safety.

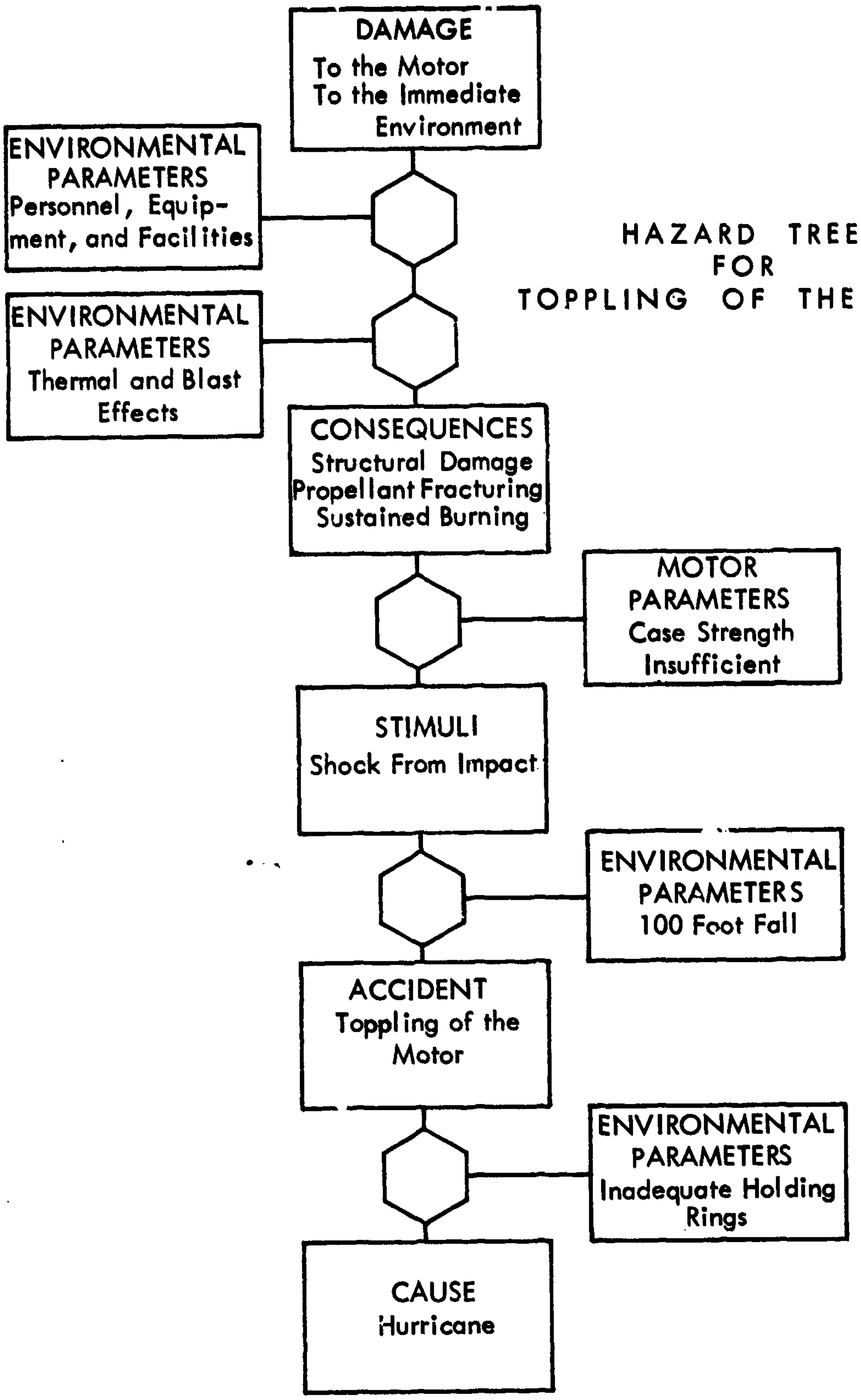
At this stage of development, the hazard tree can also provide a guide for management decisions regarding the allocation of resources for design changes, development of operational procedures, or other means for improving safety; or for conducting special tests and research efforts required to establish environmental and motor parameters.

(Slide 1 narrative)

The advantage of the hazard tree can be examplified in slide 1 by describing the sequence of analysis for structuring the hazard tree for the potential incident.

"A hurricane with 110 mile per hour peak gusts comes out of the Atlantic and catches Cape Kennedy with its rockets up. The holding rings on the tower can only support the rocket in winds up to 95 miles per hour. The rings give way and the large solid-propellant rocket motor topples to the ground from 100 feet and impacts with the launch platform. For an impact of this magnitude, the case strength is exceeded and the initiation threshold of the propellant is reached so that structural damage, propellant fracturing, and sustained burning occur. The thermal and blast effects of the propellant deflagration result in a loss of human lives, millions of dollars in damages to the motor and tower, and months of valuable time and a damaging blow to public opinion.

HAZARD TREE
FOR
TOPPLING OF THE MOTOR



SLIDE 1

IMPACT OF CONFINED COMPOSITE PROPELLANT

In order to assess the hazards by the system approach, the behavior of the propellant mass under conditions encountered during possible incidents or malfunctions must be studied. Current efforts for defining hazard potential criteria are generally divided among the three areas of reaction kinetics, propellant detonability, and initiation sensitivity. Composite propellant reaction kinetic studies at shock temperatures and pressures have, as their long range goal, the prediction of the hazard potential in accident situations. The progress of the large solid motor program, however, required more immediate answers than could be obtained from reaction kinetic studies.

Existing laboratory test methods were investigated for applicability to defining initiation criteria of composite propellants and have not provided adequate solutions for the larger diameter motors. Composite propellant detonability studies carried out under Project Sophy utilized explosive initiators which far exceed the energy input that would be obtained in some accident situations. In effect it resulted in a maximum yield which constitutes a limiting condition because of the size of the stimulus. Flying plate impact

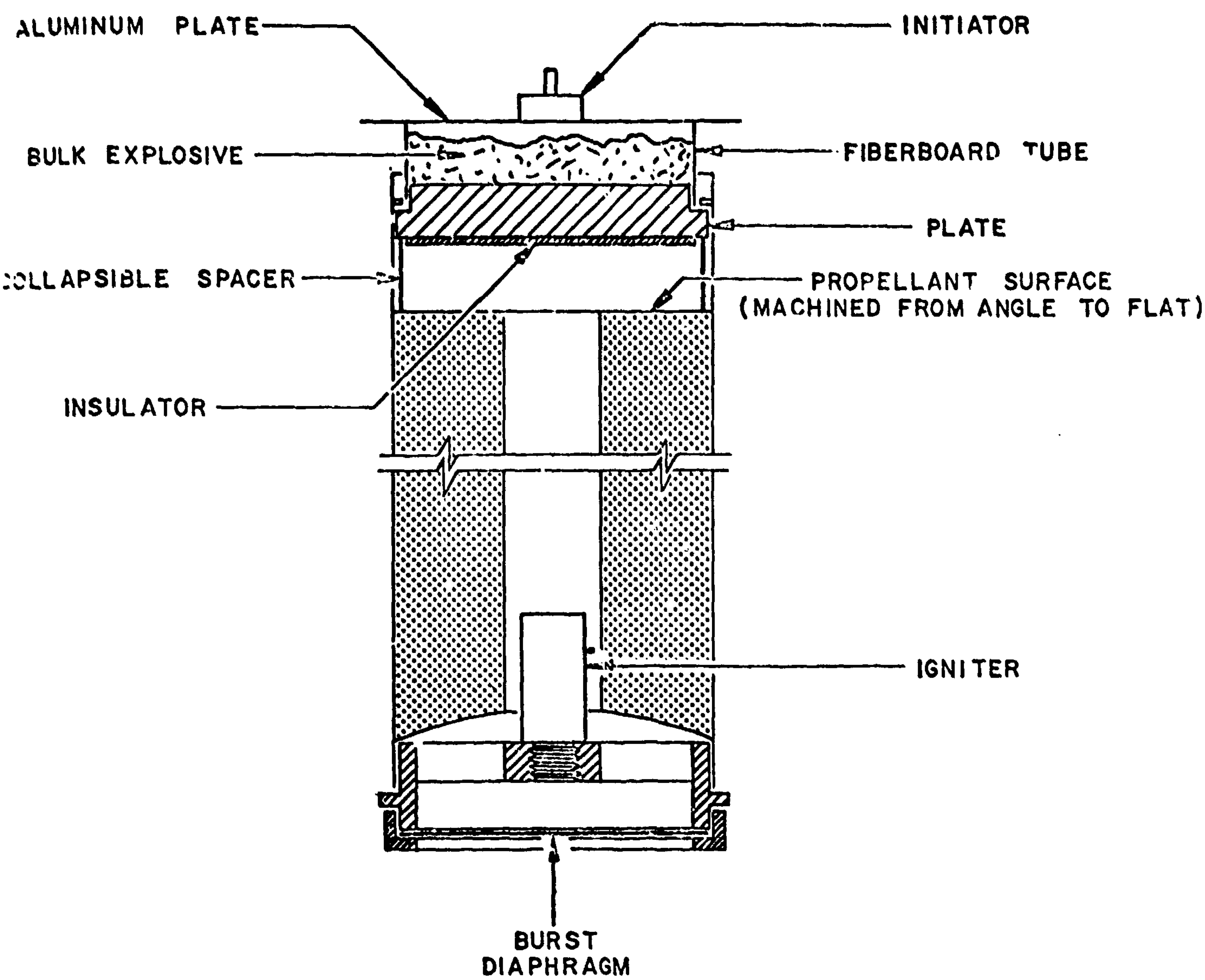
tests with some Minuteman motors by Hercules and a 120-inch diameter motor sled impact test at Naval Ordnance Test Station have been conducted in an attempt to simulate the hazards from the ground impact of a motor from a launch malfunction. These latter motor tests were useful; however, the data is limited. Of utmost importance, the tests did not provide any confinement of the motor upon impact, a condition which may significantly affect the results.

It will be necessary to develop new classification tests and concepts to define the hazards relating to large masses of propellant. Since mechanical shock is the most prevalent force expected in accident situations an evaluation of the effects of mechanical impact on propellant breakup or fracture is of primary importance, especially for composite propellant grains for which a brittle or "glass" fracture condition is thought possible. Efforts to develop a new classification test have been initiated by Illinois Institute of Technology Research Institute (IITRI) in their investigation of impact initiation with some crushing and pinching based on a technique developed for explosives. IITRI's work has been on a small scale using unconfined samples. It is felt that confinement could have an important effect.

Explosive yields will result from the high mass decomposition rate and rapid pressure rise created by the large burning surface of fractured propellant. If the burning surface is not very large, extreme confinement is necessary to obtain a transition from burning to explosion. This relation of fracturing and confinement to the resulting reaction possible must be investigated to properly evaluate potential hazards with large solid motors.

As a first effort a limited investigation of propellant response to mechanical impact under confined conditions was proposed. An explosive-driven metal plate will be utilized to mechanically fracture a confined, composite propellant grain.

It is planned to impact the composite propellant grain of the Sidewinder IC rocket motors with a calibrated explosive-driven metal plate. The motors will be mounted in a vertical position with earth confinement as shown in Slide 2. The explosive-driven plate will be arranged as shown in Slide 2. The propellant will be impacted without deforming the motor case to allow most of the input energy to be absorbed by the propellant. This technique will remove the factor of case deformation from test result interpretation. Confinement effects of the motor case are still existent to represent actual motor hazards. In addition, earth fill around the motor



SLIDE 2 - DETAIL OF EXPLOSIVE - DRIVEN IMPACT ARRANGEMENT

will simulate the confinement resulting from ground impact conditions. Other simulation of impact conditions will consist of: (a) Striking the motor end-on with a plate greater in diameter than the motor, and (b) striking the motor side-on. Both burning and unignited motors will be impacted to obtain hazards data for the two conditions. The preignition of the motor will result in stress concentration at the center preparation of the motor thereby providing for a much more severe condition.

Two principal means of evaluating the hazard potential will be (1) measurements of blast overpressure and (2) initiation conditions. Both direct and indirect determinations of overpressure will be made with instrumentation as follows:

Type	Transducers	Response Time
Direct	Strain gage type	30 KC
Direct	Piezo electric overpressure gages	50 KC
Indirect	Time-of-arrival	
Indirect	"Bikini" gages	

The instrumentation array consists of 3 legs 120° apart. Time-of-arrival techniques will be utilized as a backup system. By determining the time difference between signal arrival at two gages and knowing their distance relative to the explosion,

the overpressure can be calculated.

A photographic record will be made of each test, permitting additional analysis of the results. The initiation characteristics will be evaluated on the basis of force, velocity of impact and energy transmitted to the propellant.

With this test series we hope to accomplish:

(a) A qualitative determination of the fracturing and initiation criteria of composite propellant associated with varying impact velocities.

(b) A qualitative indication of the effect of mechanical impact under conditions of confinement on the type of reaction obtained. These tests will be applicable to defining the potential blast hazard and damage potential associated with large solid motors if explosive reactions occur.

(c) A comparison of the explosive yields of the "ignited-after-impact", "initiated-by-impact", and "ignited-prior-to-impact" motors. This data will be applicable to analyzing rocket motor handling and operational procedures for accident severity and damage potential.

(d) A comparison of the impact force required to initiate an explosion reaction in nonburning and burning motors.

FRACTURING OF PROPELLANT BY SHOCK

Considerable effort has been directed to defining the detonability of a given composite propellant system. However, with this information a major problem area remains unsolved and that is that of violent reactions without a true detonation occurring. To assess the realistic potential hazards of larger solid motors, we have placed emphasis on the explosion hazards including:

a) Nondetonation reactions

b) Energy release as function of time

c) Blast effects

Under (a) we studied the conditions that may cause transition of a burning propellant to explosion or detonation. Knowledge about the energy release under (b) is required to develop a blast wave model for assessing the explosion hazard more realistically. The blast wave expected from composite propellant is often defined in terms of its TNT equivalence. This TNT equivalence is estimated and poorly represents the blast wave of nondetonative reactions. More accurately, the physics and kinetics of the nondetonative reaction must be taken into consideration. Experimental studies of blast waves structure are difficult to conduct, and a theoretical

model is required to describe the structure of the blast for predicting the damage from an explosion reaction. To assess the hazards of a large motor under conditions of impact, the physical behavior of composite propellant must be considered to describe the mechanism and rate of propellant breakup and its influence on the resulting reaction.

The initiation mechanism, subsequent explosion and/or detonation reaction characteristics and the energy release of a propellant are sensitive functions of properties such as porosity and the fracturing mechanism of the propellant. It is known that high local pressure can cause surface cracking and thus lead to additional burning area which might quickly give rise to thermal explosion. A launch malfunction will probably result in an impact velocity in the range of 100 to 1000 ft/sec, and with these impact speeds, the shock pressure is not expected to exceed 15 kilobars. Of particular interest then is the fracture behavior of a propellant when shock loaded up to 15 kilobars. Since this pressure range may be too low to initiate detonation without considerable confinement but high enough to cause violent explosions, there is a critical need for determining the explosion hazard of the propellant subjected to these shock pressures.

In second effort we try to develop quantitative relationships of impact shock, propellant surface increase, and combustion transients. The more sophisticated instrumentation and analytical techniques available for testing on a laboratory scale will provide better control of the experiments and a more accurate determination of results. It is attempted to answer the following:

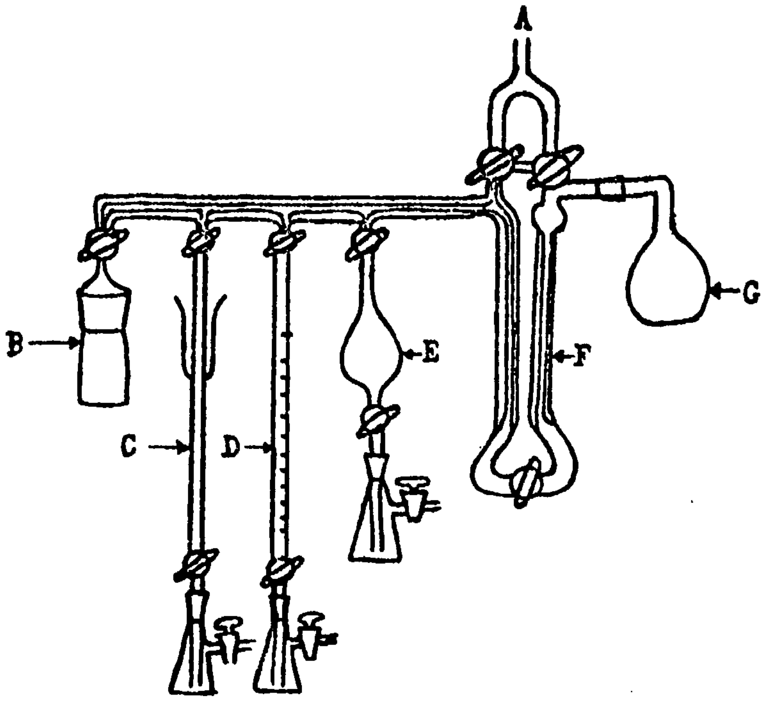
a) How does the propellant anticipated for use in large motors behave when exposed to shock?

b) To what extent does shock loading increase the surface area available for combustion?

c) Is the increase in surface area under realistic impact conditions sufficient to cause a transition from burning to explosion or detonation?

An impacting technique to generate shock waves of varying magnitudes in the propellant sample is being used. The method is (a) one dimensional and has (b) well defined shock wave (ampliture and duration) and (c) allows a quantitative collection of the reaction product.

The propellant is cast in a cylindrical casing of matching shock impedance. The sample casing assembly is subjected



SLIDE 3

to the impact of a traveling projectile that exposes the sample to a square shock wave of accurately known pressure and duration. This part is conducted by Atlantic Research Corporation. For the surface determination an apparatus has been constructed using the Brunauer-Emmett-Teller method but adapted to samples of very low specific surfaces. The sample may be at room or liquid nitrogen temperatures. A variety of gases or vapors may be used, dependent upon the characteristics of the sample. The setup is illustrated in the following slide - Slide 3.

The apparatus is connected to a high vacuum line at A. The sample is contained in B (B as illustrated is designed primarily for determinations with water vapor at room temperature. A slightly different design may be desirable for determinations with such gases as nitrogen, oxygen, etc., at low temperatures). The apparatus is designed such that the volume in E can be adjusted to equal the "dead" volume in B, and the gas absorbed can then be read directly on the graduated buret, D. For maximum accuracy, the "dead" volume is kept as small as possible. The primary function of G is simply to serve as a pressure ballast, but it can

also be used to out gas the manometer fluid. The manometer fluid is a liquid of relatively low density, low vapor pressure, and with poor solvent properties for the gases or vapors being used.

The measured surface increase will be correlated to be impacting pressure. In a third phase transient combustion phenomena will be determined as a function of the surface area.

ACKNOWLEDGMENT

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THE PROPERTIES AND PERFORMANCE OF FRAGMENTS

by

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To begin with, it should be noted that flight characteristics of any irregularly shaped body are difficult to predict. However, as in the case of fragments, when the need for data arises the best possible methods are utilized to fulfill the need. At the Naval Weapons Laboratory, it became necessary to compute fragment trajectories in order to determine minimum safe release altitudes for low altitude dive bombing such that the delivery aircraft is not endangered by fragments projected from a delivered weapon. This discussion will be with respect to methods and assumptions used at NWL in the computation of fragment tra_ .ctory data.

First, let us look at the assumptions to be made and inputs necessary to compute fragment trajectories:

(1) Fragment motion during flight

(2) Coefficient of drag

(3) Reciprocal ballistic coefficient

(4) Initial velocity

(5) Elevation angle

(6) Equations of motion

Fragment Motion During Flight

Based on a literature survey of experimental data, the most reasonable assumption of fragment motion during flight is that fragments fly in

accordance with the uniform orientation hypothesis (i.e., all orientations of the fragment are equally probable). This leads directly to the assumption of the average fragment area being presented to the airstream for the purposes of determining a drag coefficient.

Coefficient of Drag

The drag coefficient used at NWL is based on firings of fragments conducted at the Ballistics Research Laboratories. The C_D data derived from these firings were based on fragment presented areas determined in accordance with the uniform orientation hypothesis. Figure 1 shows the drag curve after being modified for use with particle equations of motion used at NWL.

Reciprocal Ballistic Coefficient ($\gamma = A/W$)

The reciprocal ballistic coefficient, γ, is computed as the ratio of average presented area to weight (A/W). This ratio is determined by measuring a representative sample of fragments on an icosahedron gauge. In effect, this gauge measures the projected area from 20 different views which correspond to the normals to the faces of an icosahedron. These 20 areas are averaged to obtain the average presented area. Having the presented areas and weights for a representative sample of fragments from a given weapon, a least squares fit is made to the data. The general form of the equation is

$$A/W = kW^c$$

where k and c are constants determined from the least squares fit.

Initial Velocity

Average fragment velocity ($\bar{V}$) data are obtained by recording with high speed cameras the time from weapon detonation to fragment impact on witness panels. Initial velocity (V_o) data are derived by

$$V_o = \bar{V} \quad \frac{e^w - 1}{w}$$

where $w = \frac{1}{2}\rho\gamma C_D R$ and

- ρ is the air density
- γ is the reciprocal ballistic coefficient
- C_D is the drag coefficient and
- R is the fragment travel distance

Elevation Angle

The elevation angle is determined from the combination of weapon orientation angle at detonation and fragment departure angle from the weapon.

Equations of Motion

Standard particle equations of motion are used to integrate the fragment trajectories.

Trajectory Variation

For the purpose of looking at fragment trajectory deviation, a typical set of conditions were assumed:

Fragment Weight : 40 grams

Initial Velocity: 4000 ft/sec

Elevation Angle : 45 degrees

Figures 2, 3 and 4 show horizontal velocity versus horizontal travel, vertical velocity versus vertical travel and total velocity versus slant range respectively. All three figures show the rapid decay of velocity during the first fraction of a second. This is due to the extremely high drag values through the transonic and supersonic velocities.

Table 1 shows the difference in horizontal range due to a velocity difference of 500 ft/sec for a 40 and 200 gram fragment. As would be expected, due to high supersonic and transonic drag, this initial velocity difference gives a very small difference in horizontal range. In the determination of release altitude data only the first few seconds of the fragment's trajectory is usually involved. The errors in range at these times are correspondingly reduced.

Figure 5 gives horizontal range versus elevation angle for fragment weights of 20 to 200 grams. It is noted that the elevation angle for maximum range is between 25 and 30 degrees for the weights considered. The elevation angle for maximum range will increase as the area-to-weight ratio decreases.

It should be pointed out that we know of no way of precisely verifying the release altitude data determined by these methods. Reports received from the Fleet users of the data have been favorable, however. Those who have returned with fragment damage have invariably admitted violating the established minimum safe release conditions in some way. The violations are usually gross and do not tell us just how accurate the release data are.

For the purposes of determining safety areas and/or barricading around buildings, etc. containing explosives, one will have to know more about the actual materials that fragment. For instance, the initial velocity, departure angle, area-to-weight ratio and coefficient of drag for concrete chunks, large metal slabs, etc. must be determined in order to know the range over which debris may travel in the event of accidental explosion. A more reasonable approach may be to construct barricades such that only fragments departing at high elevation angles and corresponding short range fragments can be projected into the surrounding areas.

HORIZONTAL RANGE ERROR DUE TO 500 FT/SEC INITIAL VELOCITY ERROR

45° Elevation Angle

Fragment Weight (gm)	Initial Velocity (ft/sec)	Range (ft)	Range Error (ft)
40	4000	1499	28
40	4500	1527	
200	4000	2135	43
200	4500	2178	

Table 1

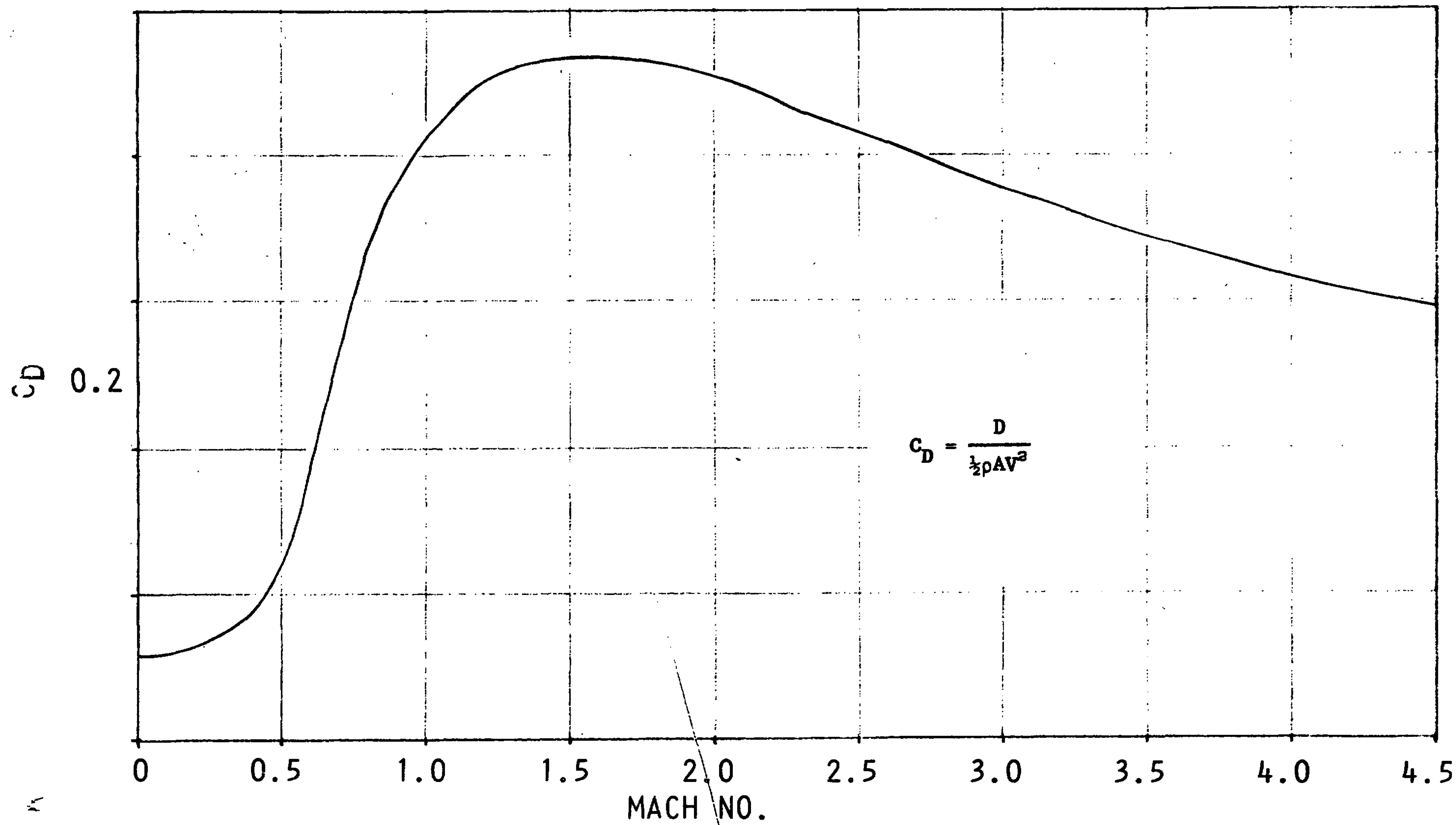

Figure 1

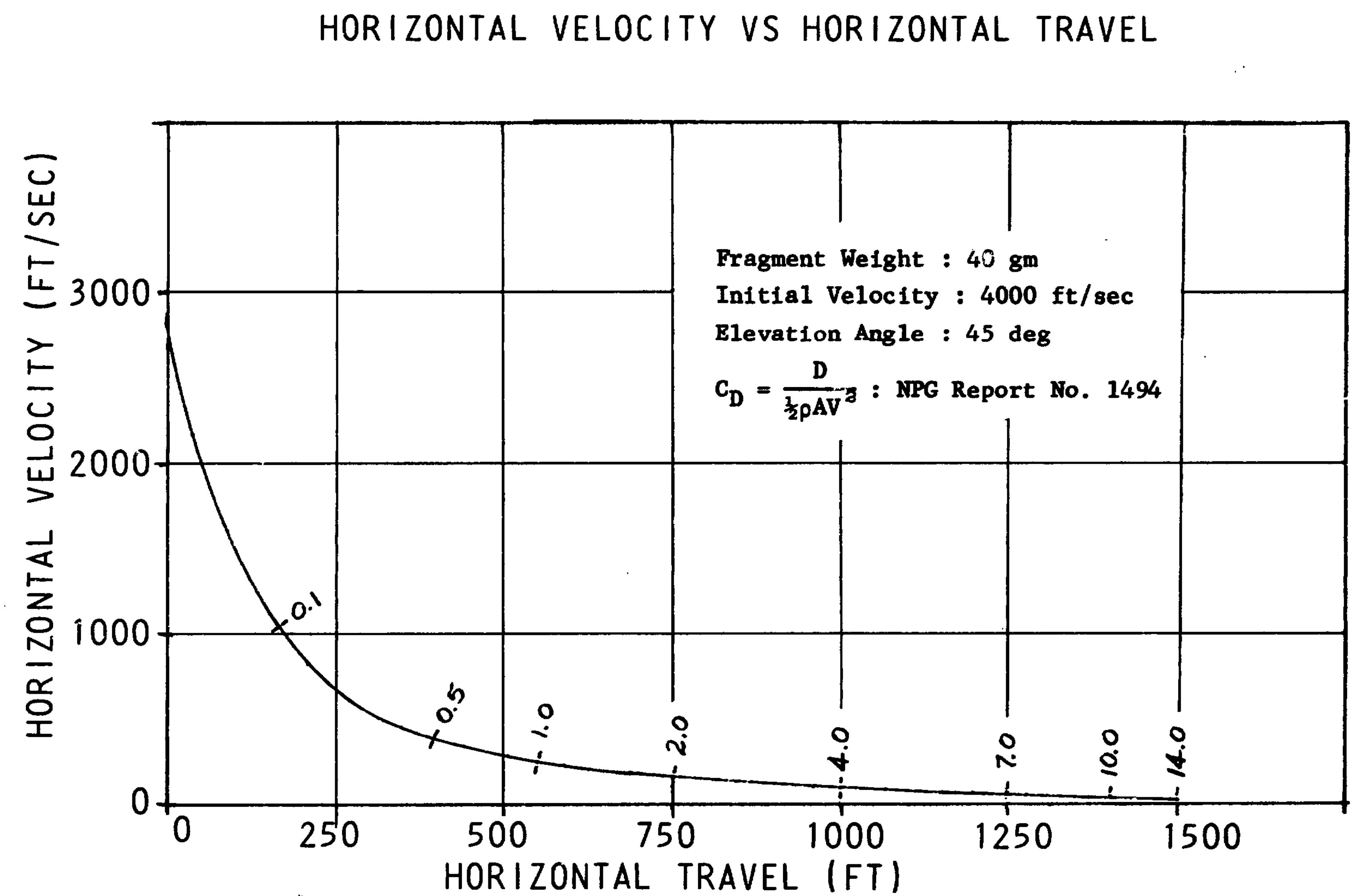
HORIZONTAL VELOCITY VS HORIZONTAL TRAVEL
Fragment Weight : 40 gm
Initial Velocity : 4000 ft/sec
Elevation Angle : 45 deg
$C_D = \frac{D}{\frac{1}{2}\rho AV^2}$: NPG Report No. 1494
HORIZONTAL VELOCITY (FT/SEC)
3000
2000
1000
0
HORIZONTAL TRAVEL (FT)
0
250
500
750
1000
1250
1500
0.1
0.5
1.0
2.0
4.0
7.0
10.0
14.0

Figure 2

VERTICAL VELOCITY VS VERTICAL TRAVEL

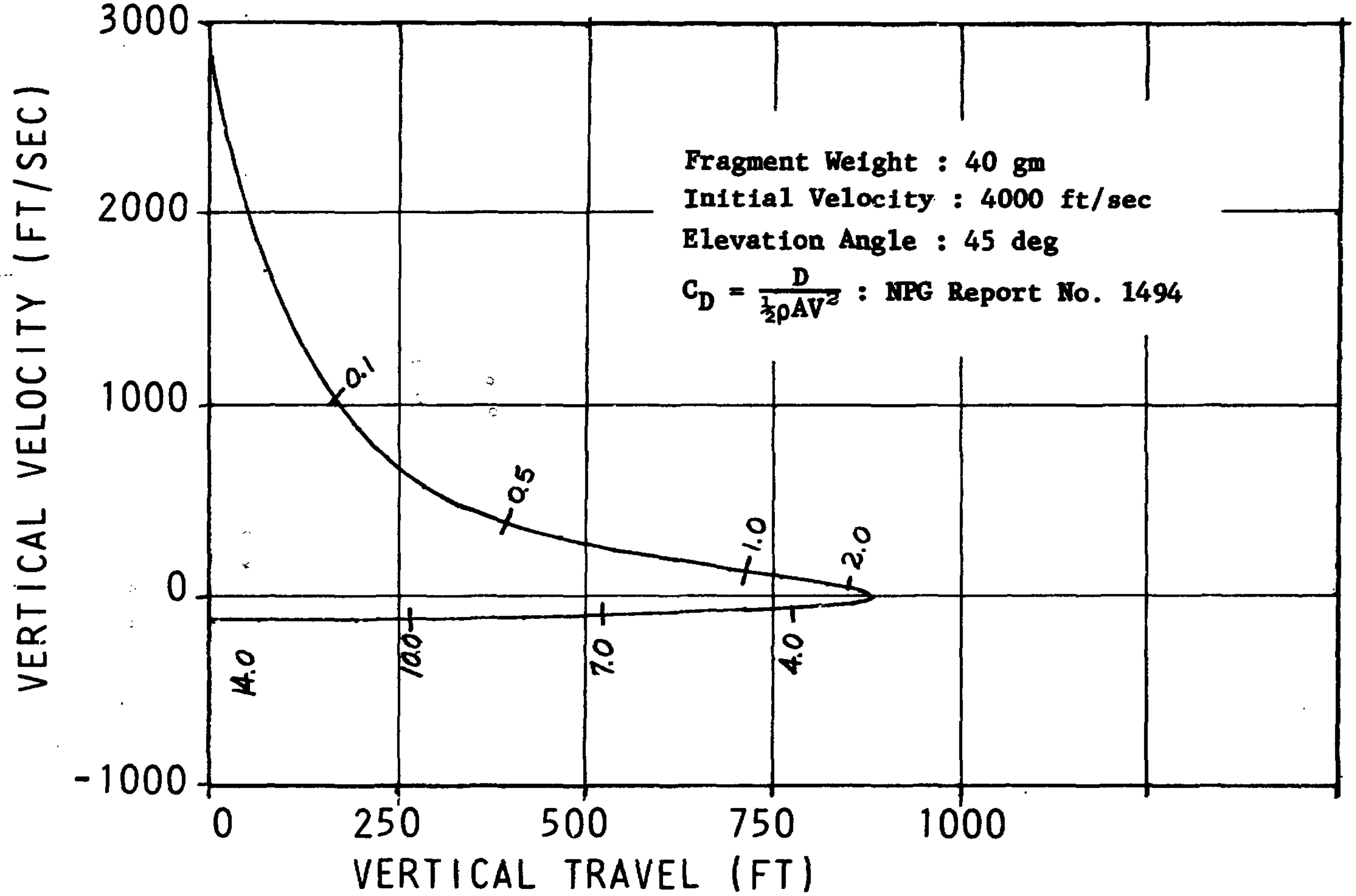

Figure 3

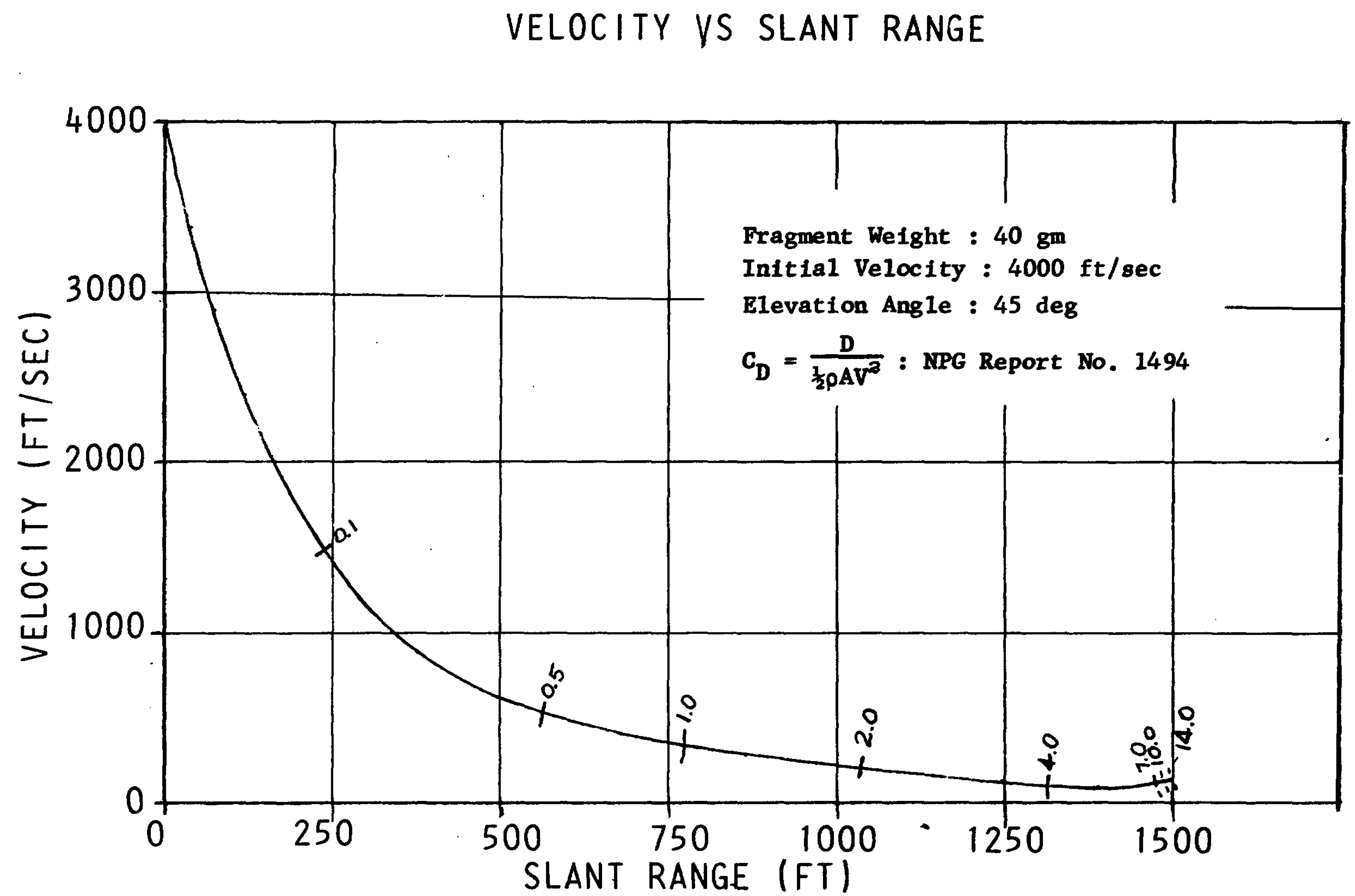
VELOCITY VS SLANT RANGE
Fragment Weight : 40 gm
Initial Velocity : 4000 ft/sec
Elevation Angle : 45 deg
$C_D = \frac{D}{\frac{1}{2}\rho A V^2}$: NPG Report No. 1494
VELOCITY (FT/SEC)
4000
3000
2000
1000
0
SLANT RANGE (FT)
0
250
500
750
1000
1250
1500
0.1
0.5
1.0
2.0
4.0
7.0
10.0
14.0

Figure 4

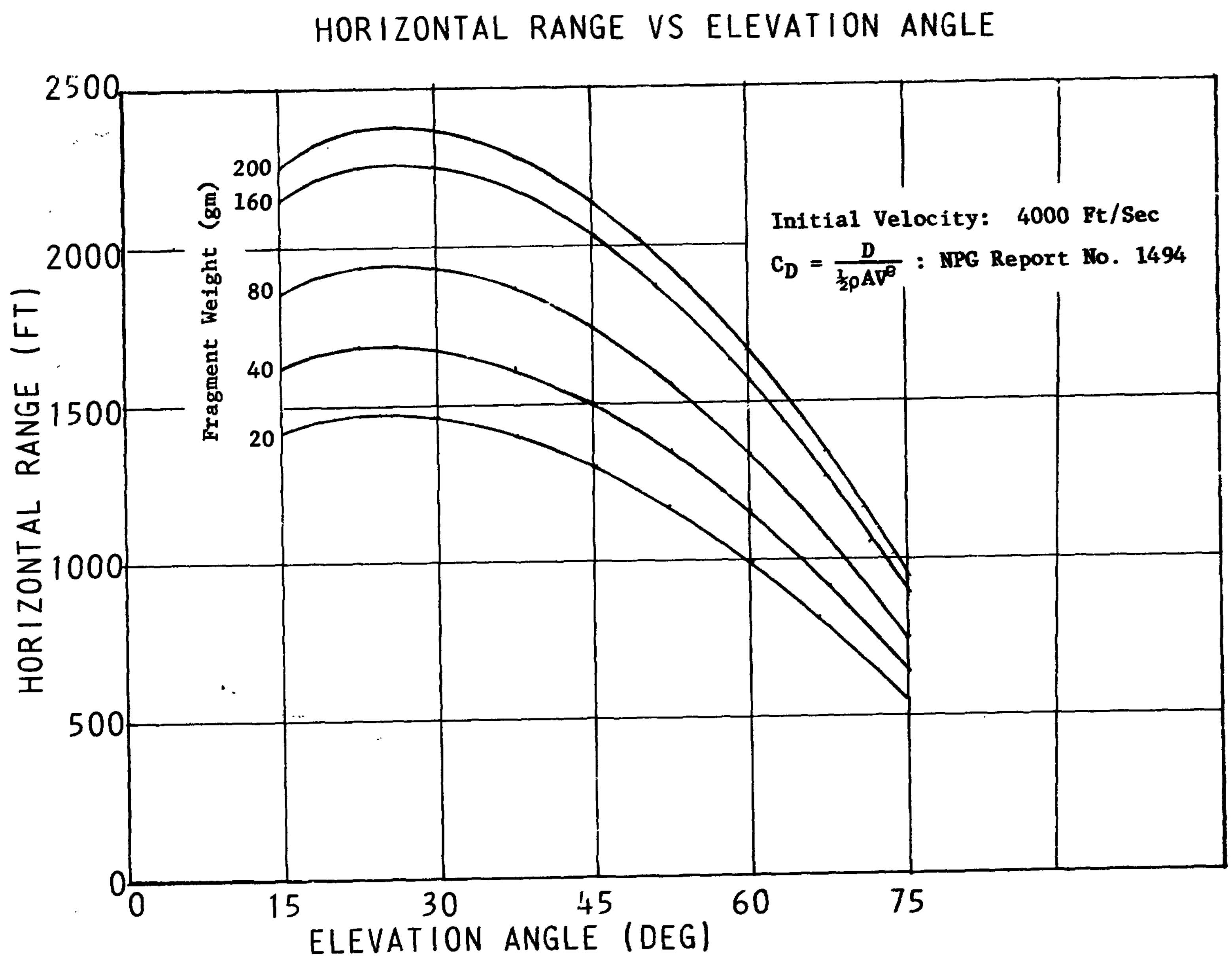
HORIZONTAL RANGE VS ELEVATION ANGLE
Initial Velocity: 4000 Ft/Sec
$C_D = \frac{D}{\frac{1}{2}\rho A V^2}$: NPG Report No. 1494
Fragment Weight (gm)
200
160
80
40
20
HORIZONTAL RANGE (FT)
2500
2000
1500
1000
500
0
0
15
30
45
60
75
ELEVATION ANGLE (DEG)

Figure 5

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THE MECHANICAL PROPERTIES OF PROPELLANT AT HIGH RATES OF LOADING

by

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A presentation given at the Armed Services Explosive Safety Board Meeting, San Diego, California, 16 August 1967.

ABSTRACT

Solid propellants used in modern high performance rocket motors exhibit viscoelastic behavior. Thus, the stress-strain response is considerably modified by such parameters as temperature and rate of strain. Typically, at high temperatures or low strain rates, the propellant behaves as a soft rubbery material with a low tensile modulus and a low tensile strength. Conversely, at low temperatures or high strain rates, the propellant exhibits brittle behavior with a high modulus and breaking strength. For a linear viscoelastic material, the principle of reduced variables enables a correlation to be established between strain rate and temperature effects. Thus, the effects of high loading rates can be predicted from moderate strain rate tests carried out at lower temperatures. Propellants do not exhibit perfectly linear viscoelastic behavior especially at or near failure so that complete correlation between temperature and rate effects is not obtained. Typical failure data for highly filled propellants are given and reviewed, and possible causes of the anomalies are discussed.

INTRODUCTION

The physical properties of propellants at high loading rates may be measured experimentally by rapidly deforming a tensile specimen in a high-rate testing machine or by testing the specimen at a high excitation frequency in a dynamic testing machine. The two types of tests are fundamentally different in that the single cycle constant rate test is usually taken to failure whereas the dynamic test is conducted at small strain amplitudes well removed from failure. The type of test is determined by the information required. Thus, studies of shock wave propagation through propellants require the modulus of the material at small deformations and here the dynamic test data would be most suitable. On the other hand, studies of propellant failure under high rate conditions would require the data obtained from the high velocity constant rate tests to failure.

PROPELLANT BEHAVIOR

Propellants are viscoelastic materials exhibiting a changing modulus with time and temperature. Applying a step strain input to a tensile specimen and measuring the relaxation modulus as a function of time gives the curves illustrated in Figure 1.

Typically, the modulus curves at all temperatures decrease with time. Also, the relaxation modulus increases as the temperature is decreased.

Time-Temperature Equivalence

Application of the time-temperature equivalence principle enables a relaxation modulus versus reduced time curve to be obtained together with the shift factor-temperature curve, as shown in Figure 2. The individual relaxation modulus curves (Figure 1) are translated along the log time axis to form a single smooth curve continuous with the reference temperature curve (usually 70°F). The resulting modulus-reduced time curve is considered to be the characteristic modulus-time curve for the material at the reference temperature. Thus, the instantaneous modulus at short time intervals corresponding to high loading rate may be obtained without carrying out high rate tests. The modulus-time curve for any other temperature is obtained by inserting the appropriate shift factor (log a_T) in the reduced time scale and bodily shifting the whole curve along the log time axis. At low temperatures the curve shifts to the right and the modulus at a specific time increases; at high temperatures the modulus curve shifts to the left.

The existence of the time-temperature equivalence principle is the main reason why high rate loading tests are not considered an essential part of a propellant testing program. Instead, the effects of high and low rates of loading are generally derived from moderate rate data determined at different temperatures.

HIGH LOADING RATE EXPERIMENTAL APPARATUS

Dynamic Testing

The principle of operation is that cyclic high frequency displacement (or stress) is applied to a specimen. Various types of testing machines employ different methods of excitation, mechanical, electromagnetic as in the Fitzgerald apparatus, or piezoelectric as in Lockheed Propulsion Company's (LPC) dynamic testing machine. The specimen may be excited in any of the common test modes, tension-compression, flexure, or shear. LPC's device (shown in Figure 3) was developed originally by Miles at Lockheed Missiles & Space Company (LMSC). It consists of a lead zirconium titanate piezoelectric crystal device applying a shearing strain to a small specimen and a force monitoring element. Amplitude and phase shift of output relative to input displacement are measured and recorded. Tests are conducted over a frequency range of 20 to 1000 cps and at temperatures from -100 to +200°F. From these data the dynamics modulus components (real or imaginary) may be determined. Typical data for propellant are shown in Figure 4.

The data show that the real modulus component can be shifted to produce a single modulus-reduced frequency curve. The damping or imaginary component does not

shift to produce a single curve since the damping modulus curves are slightly different at the different frequencies. Thus, the higher the frequency the earlier the propellant behaves like a brittle solid, and the earlier the peak in the damping modulus frequency curve is reached. These data are typical of dynamic test results on propellants.

Comparison Between Static and Dynamic Data

A comparison between a relaxation modulus curve obtained at 5% strain level and the relaxation modulus calculated from the small strain dynamic data is given in Figure 5. The dynamic moduli are approximately six times larger than the relaxation data at the same reduced time. The shift factor-temperature curves for the two sets of data were identical.

It appears that the cause of this discrepancy is that at the minute strain levels of the dynamic test, the filler particles in the propellant act as reinforcers producing the higher modulus value. However, when a strain level of 2 to 5% is applied to the propellant, as in the relaxation test, some of the filler-binder bonds are broken and some of the reinforcing effect of the filler is lost.

Single Cycle Tests

Testing machines such as the Instron may be used to obtain constant rate data at crosshead speeds up to 50 inches/minute. For higher crosshead rates, high rate machines such as the Plastechon may be used. A simple method of obtaining high strain rates is by means of a falling weight. A sketch of the apparatus used at LPC to obtain data at approximately 2000 in./in./min strain rate is shown in Figure 6. It consists of a load cell attached to the top of the frame and connected to the upper JANAF specimen holder. The lower specimen holder is attached to a long rod with a plate on the end. The rod passes through a hole in a crossbar and beneath the bar a solenoid is fixed to hold the 20-pound sliding weight prior to test. To test, the specimen is placed in the grips (supporting the weight of the rod) and then the solenoid is switched off to let the weight fall 15 inches. A photo cell and light source is used to trigger the oscilloscope time base just before the weight strikes the end plate on the rod. A Polaroid camera records the load-time trace.

A typical record obtained with propellant is shown in Figure 7, in which the load cell natural frequency vibrations are apparent. The introduction of damping in the system has not as yet been able to eliminate this load cell ringing. A specially designed high frequency load cell is probably the answer to this problem.

Strain values are usually based on the velocity of the weight and an assumed gage length, but they may be measured by means of marks on the specimen illuminated by a stroboscopic light source and photographed with a camera.

EFFECTS OF STRAIN RATE AND TEMPERATURE ON PROPELLANT FAILURE

The effects of different strain rates on a cast double-base (CDB) propellant response are illustrated in Figure 8, taken from an article by McAbee and Chmura*. Typically, the higher modulus, increased tensile strength, and reduced strain capability of the propellant, with increased strain rate, are evident. Note that the failure points of the individual tests describe a "failure locus" in stress-strain space.

A similar failure locus may be obtained by keeping the strain rate constant and changing the test temperature; Figure 9 shows CDB data from the same source. The increase in modulus and failure stress, and the reduction in failure strain with lower temperatures, are obvious from this figure.

Results on a rubber-based propellant obtained at LPC are given in Figures 10 through 13. Figure 10 shows the effect of changing the strain rate at a temperature of 77°F. The data do not look as dramatic as the CDB data because of the log scale of the plot and because of the much lower glass transition temperature of the rubber-based propellant. Similarly, the effect of temperature on the stress-strain response of the same propellant is illustrated in Figure 11. Again, reducing the temperature increases the modulus and failure stress, and reduces the failure strain as with the CDB propellant.

FAILURE LOCI

The data show that propellant failure data as well as modulus appear to obey time-temperature or strain rate-temperature equivalence. Figure 12 shows the rubber-based propellant failure data plotted as a log-stress log-strain failure envelope. Although scatter is evident, there is a great similarity between the data obtained at different temperatures and strain rates.

Another way of considering failure data obtained at different temperatures and strain rates is as a failure stress or strain versus reduced strain rate curve. Typical data for a rubber-based propellant are shown in Figure 13. Generally, failure stresses give a good plot versus reduced strain rate, whereas failure strains show more scatter.

However, the data demonstrate that the failure behavior of propellant at high loading rates may be estimated with reasonable accuracy by the use of the stress-strain failure envelope and the failure stress-reduced strain rate curves.

High rate testing that has been carried out support the use of the super-position theory although qualitative differences in stress-strain response are obtained.

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*McAbee, E., and M. Chmura, "Effect of Rate and Temperature on the Tensile Properties of Double-Base Propellant," High Speed Testing, Vol. IV, Fourth Annual Symposium, May 1963.

CONCLUSIONS

Although there is not a great deal of high strain rate test data available on propellants, the data that are available generally support the time-temperature or strain rate-temperature equivalence principle. Thus, the time- and temperature-dependent modulus and failure stress and strain may be predicted with reasonable accuracy for high rate loading conditions - even though test data are not available. Uncertainties are found at low temperatures approaching the glass transition temperature of the propellant. The data suggest that this temperature is in fact rate-dependent, such that brittle behavior is obtained at a higher temperature at high strain rates. However, over most of the normal temperature range, high rate response may be adequately predicted.

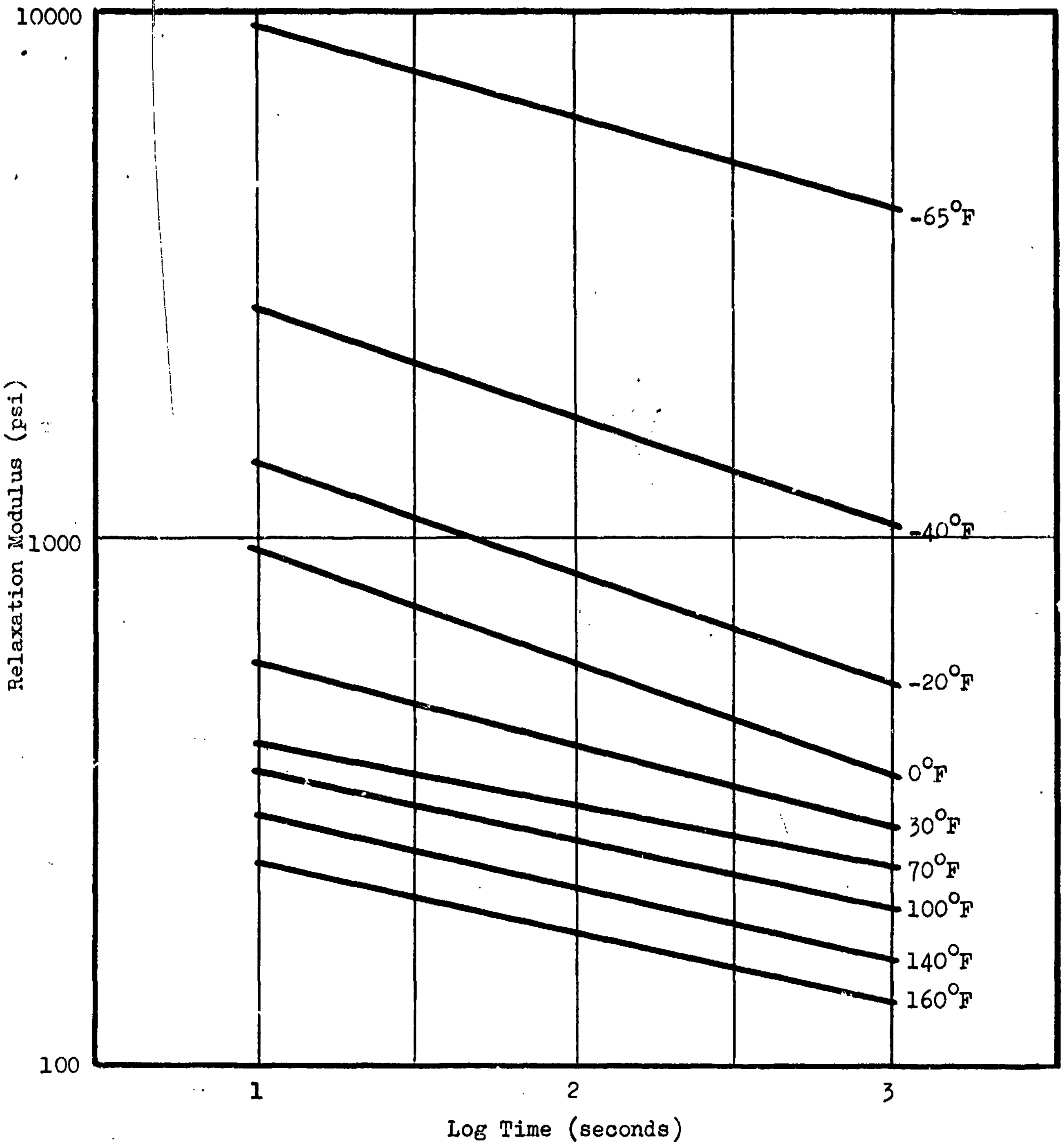

Fig. 1 LPC-580 Relaxation Modulus-Time Data

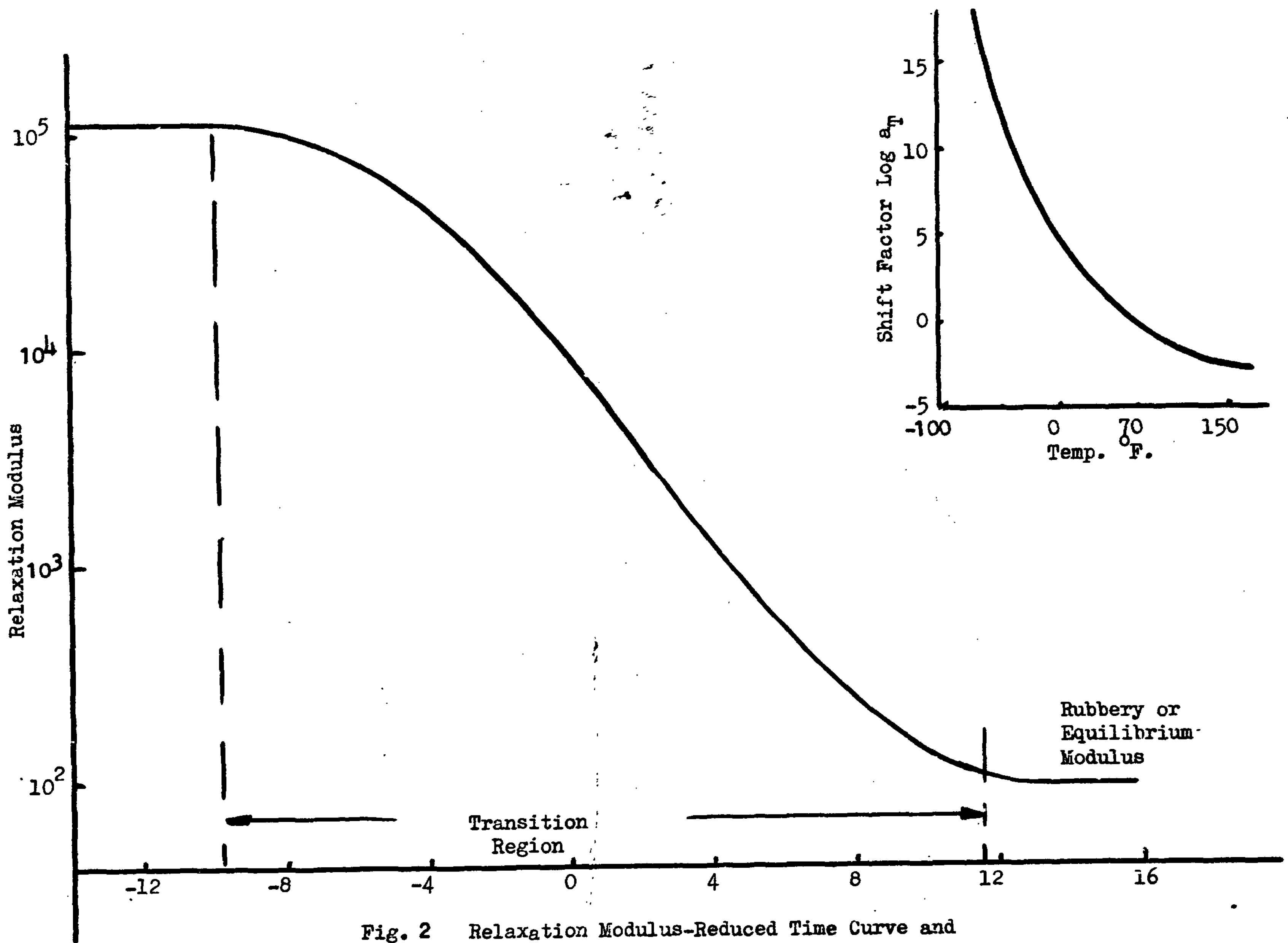

Fig. 2 Relaxation Modulus-Reduced Time Curve and Log a_T - Temperature Shift Factor Curve.

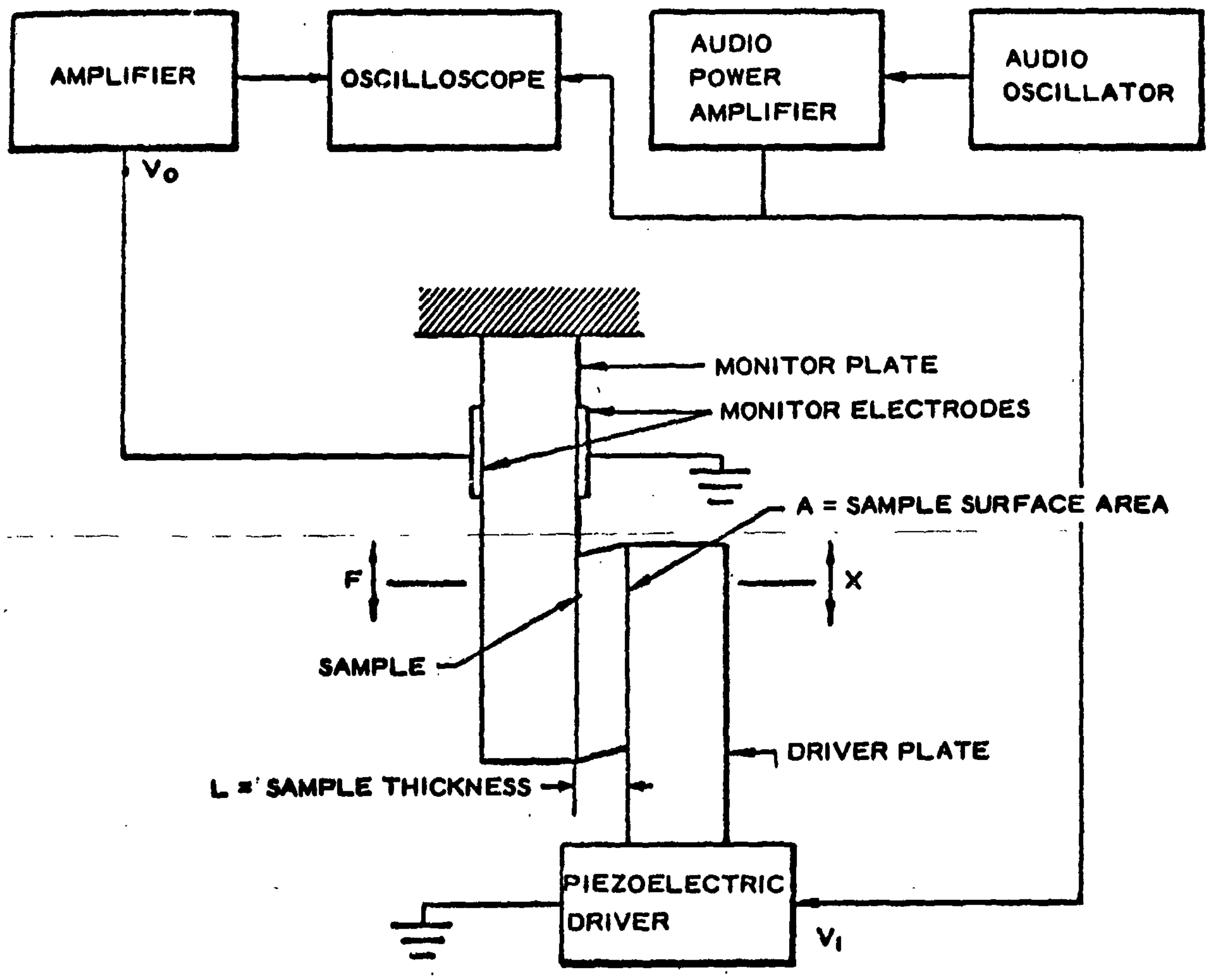

Fig. 3 Small Strain Dynamic Test System Schematic

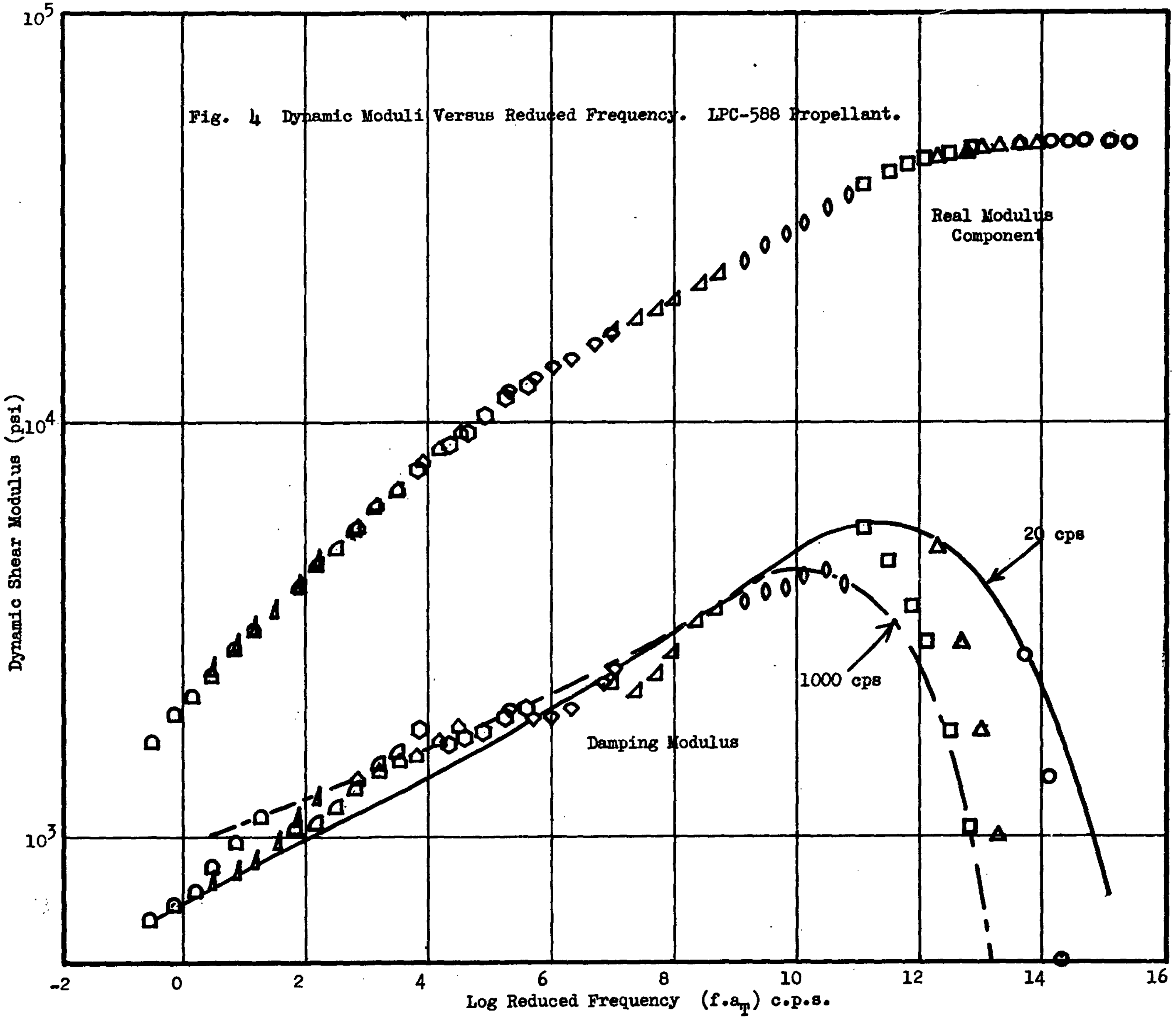

Fig. 4 Dynamic Moduli Versus Reduced Frequency. LPC-588 Propellant.

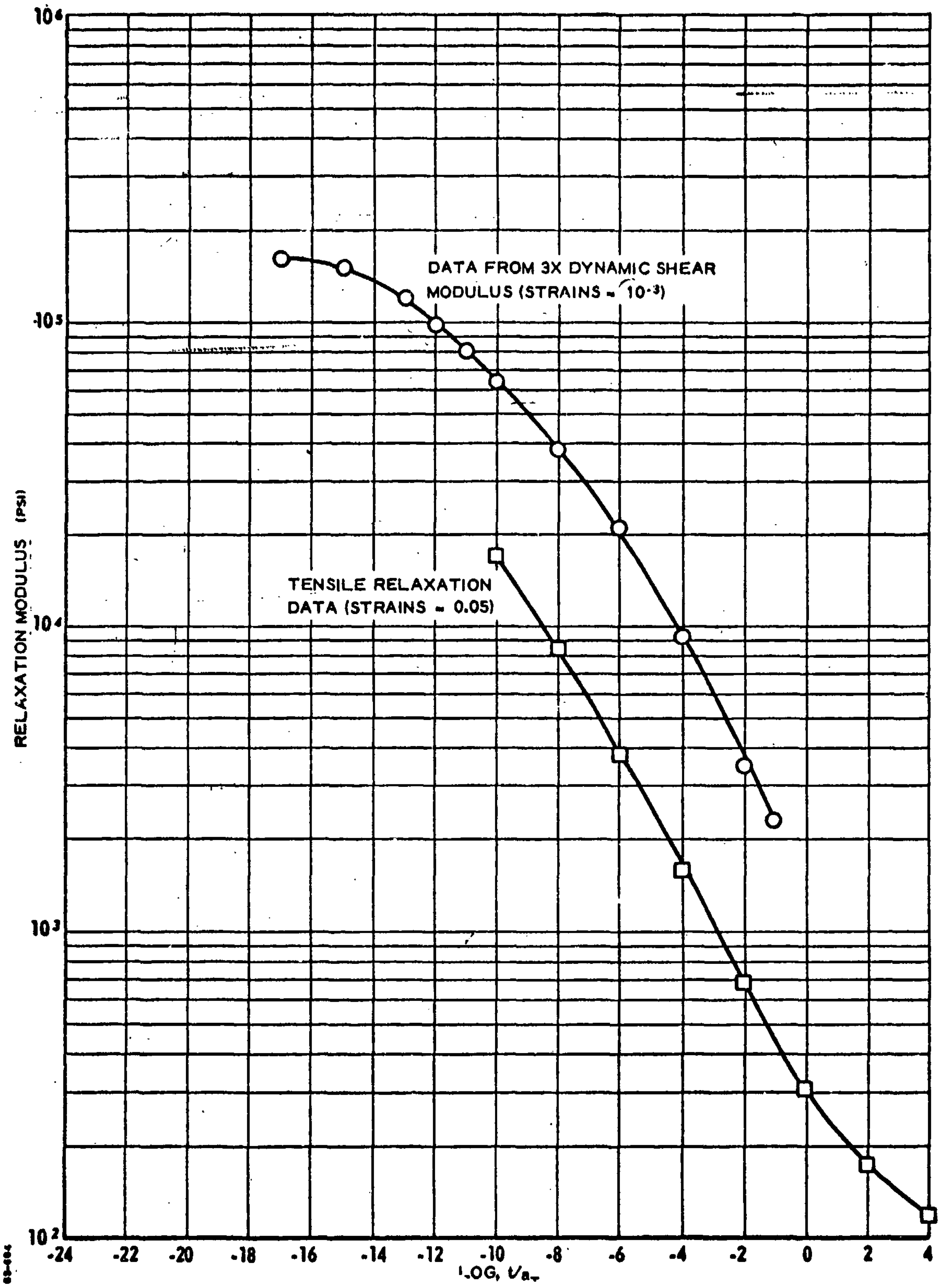

Fig. 7 Relaxation Modulus - Time Curves. NB Common Log Shift Factors Used

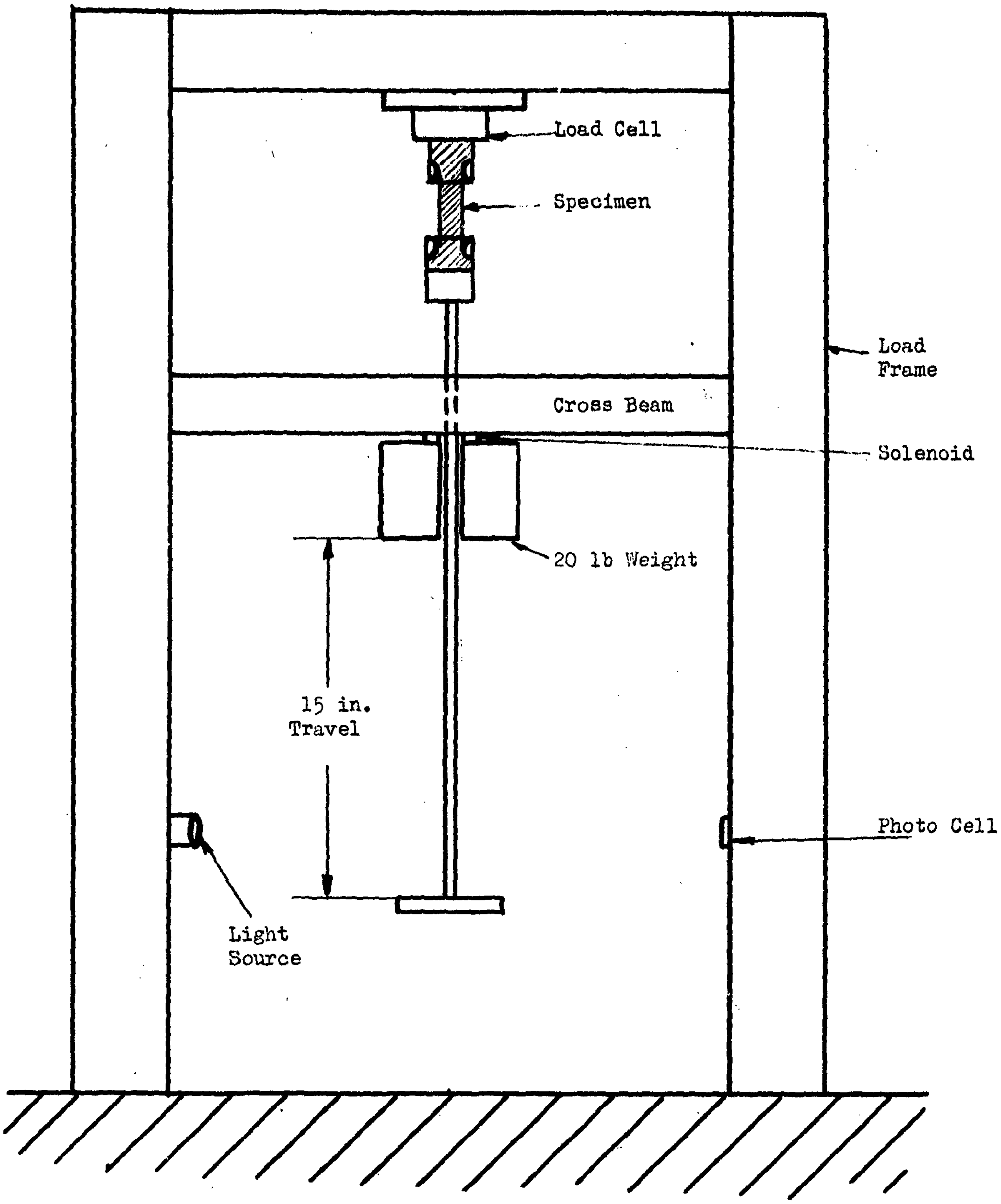

Fig. 6 Falling Weight High Rate Testing Machine

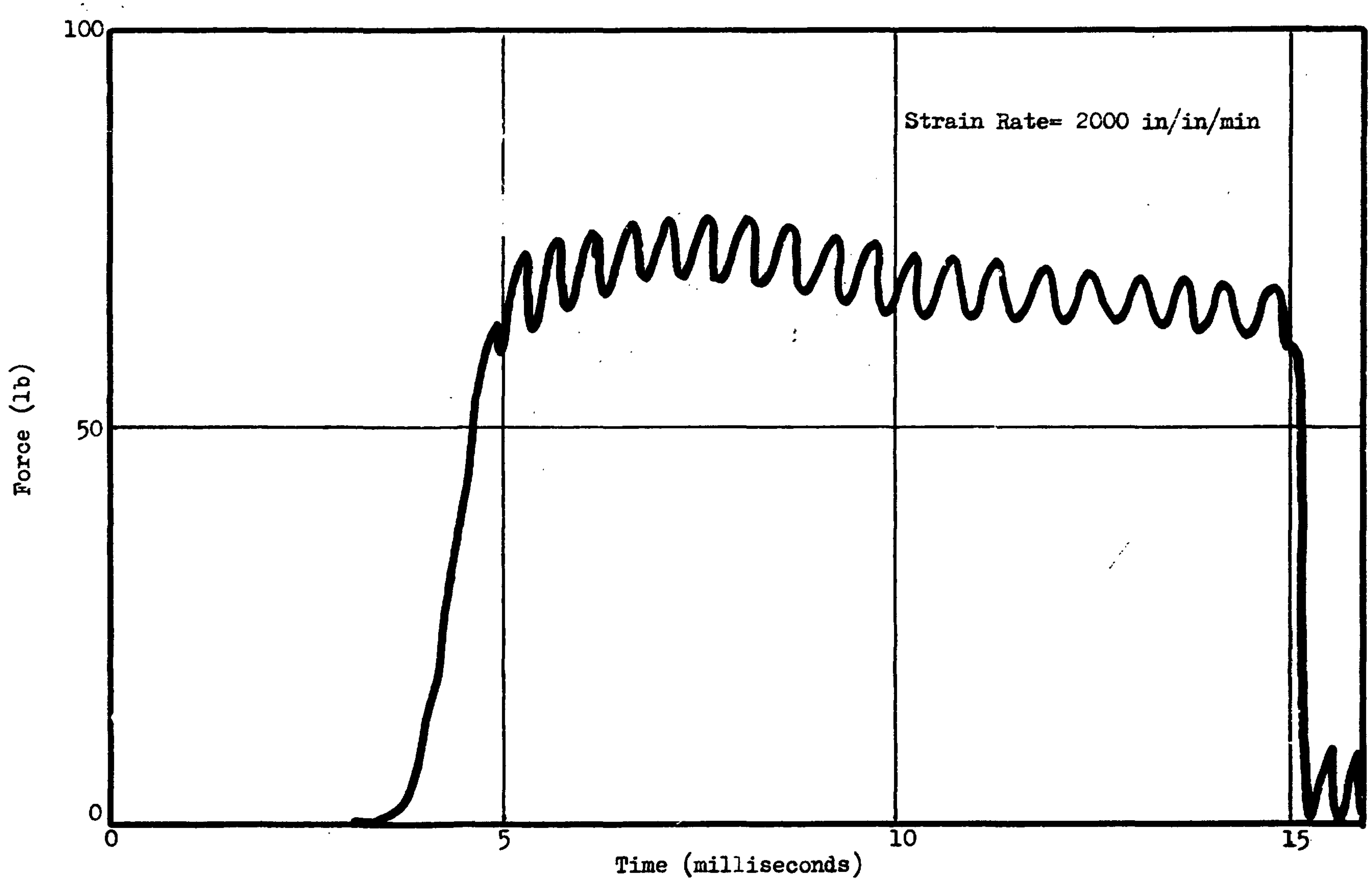

Fig. 7 Load-Time Oscilloscope Record

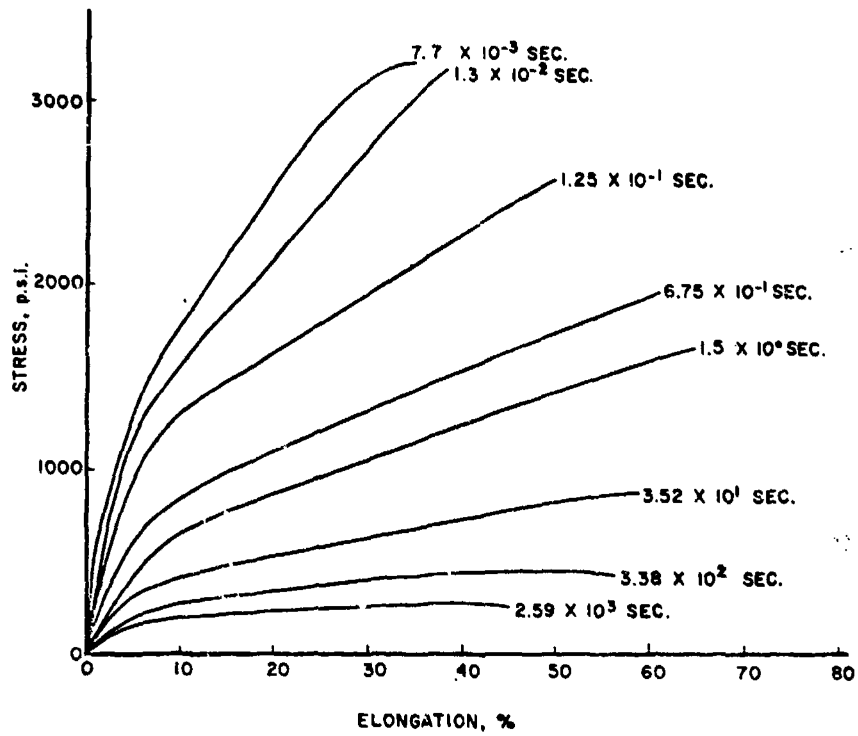

Fig. 8 Effect of Rate on the Stress-Strain Behavior of ARP at 25°C

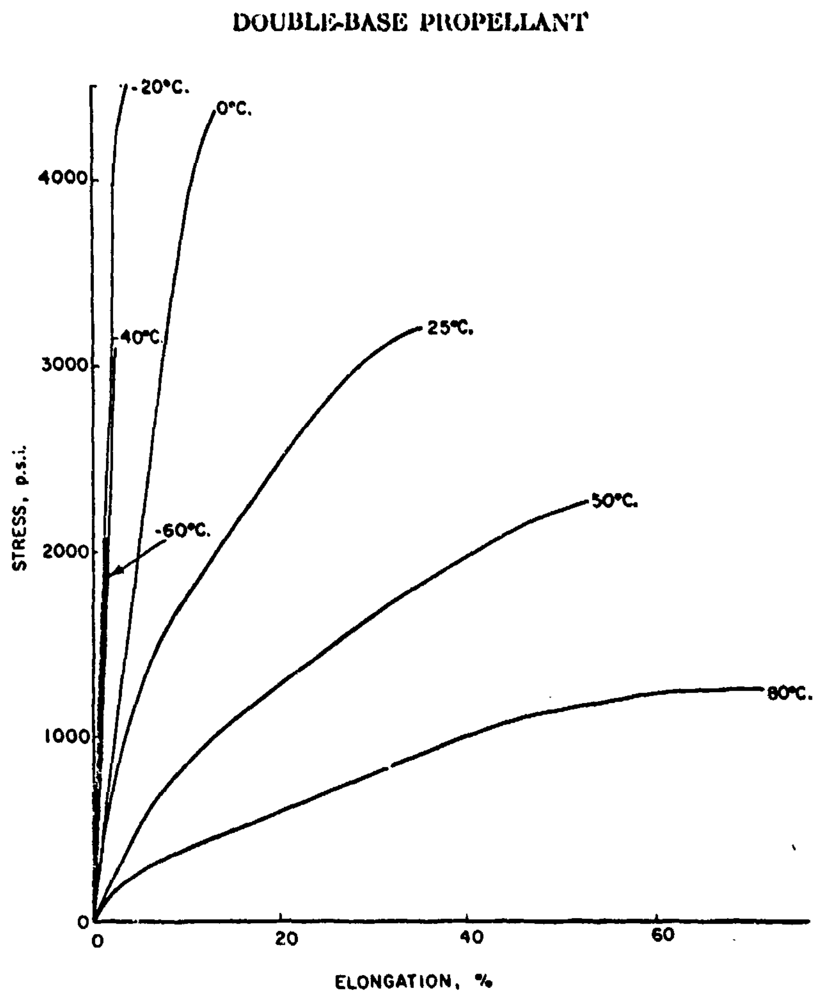

Fig. 9 Effect of Temperature on the Stress-Strain Behavior of ARP at High Rate

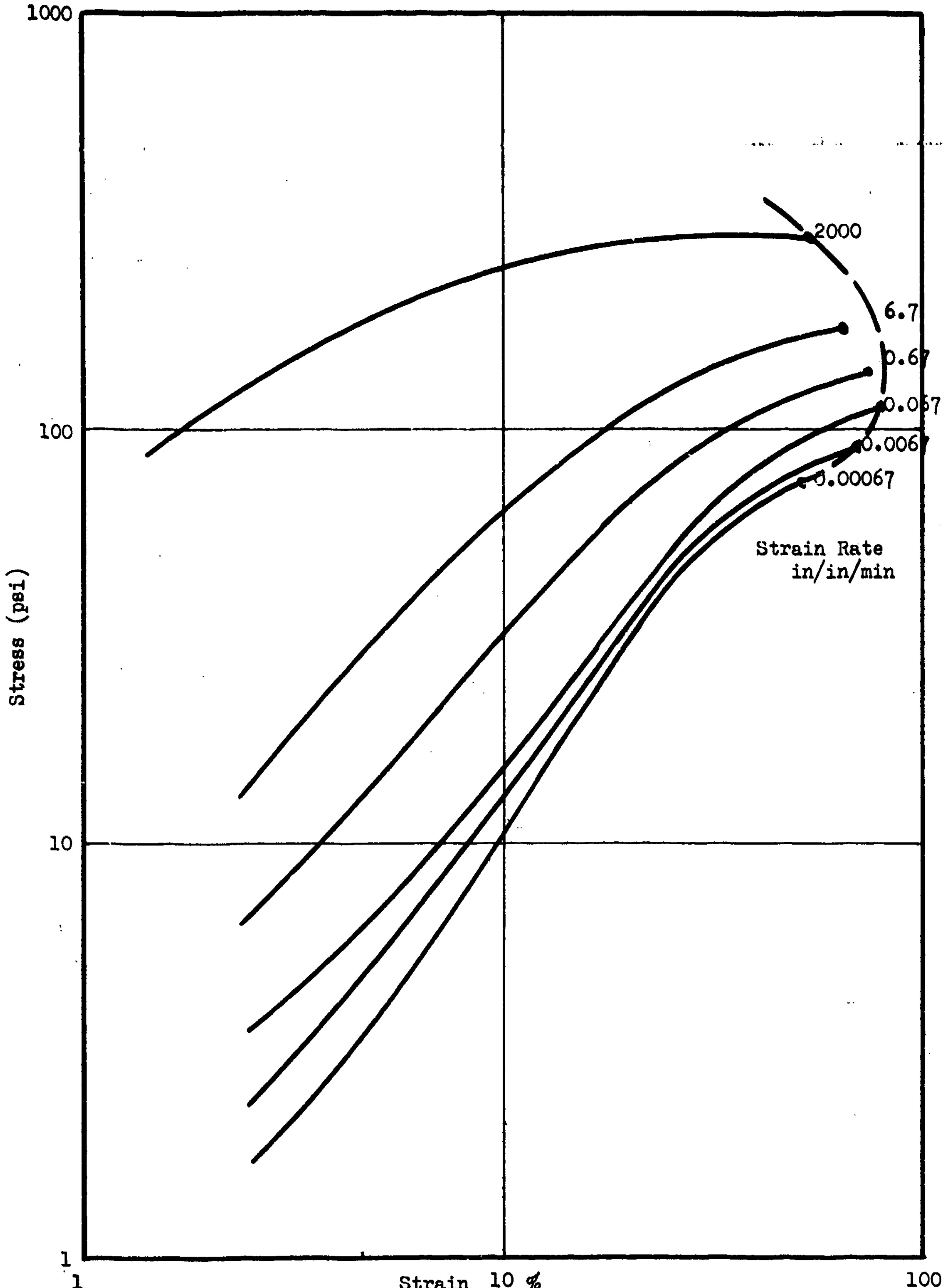

Fig. 10 Stress-Strain Response as a Function of Strain Rate. 0064-61E Propellant.

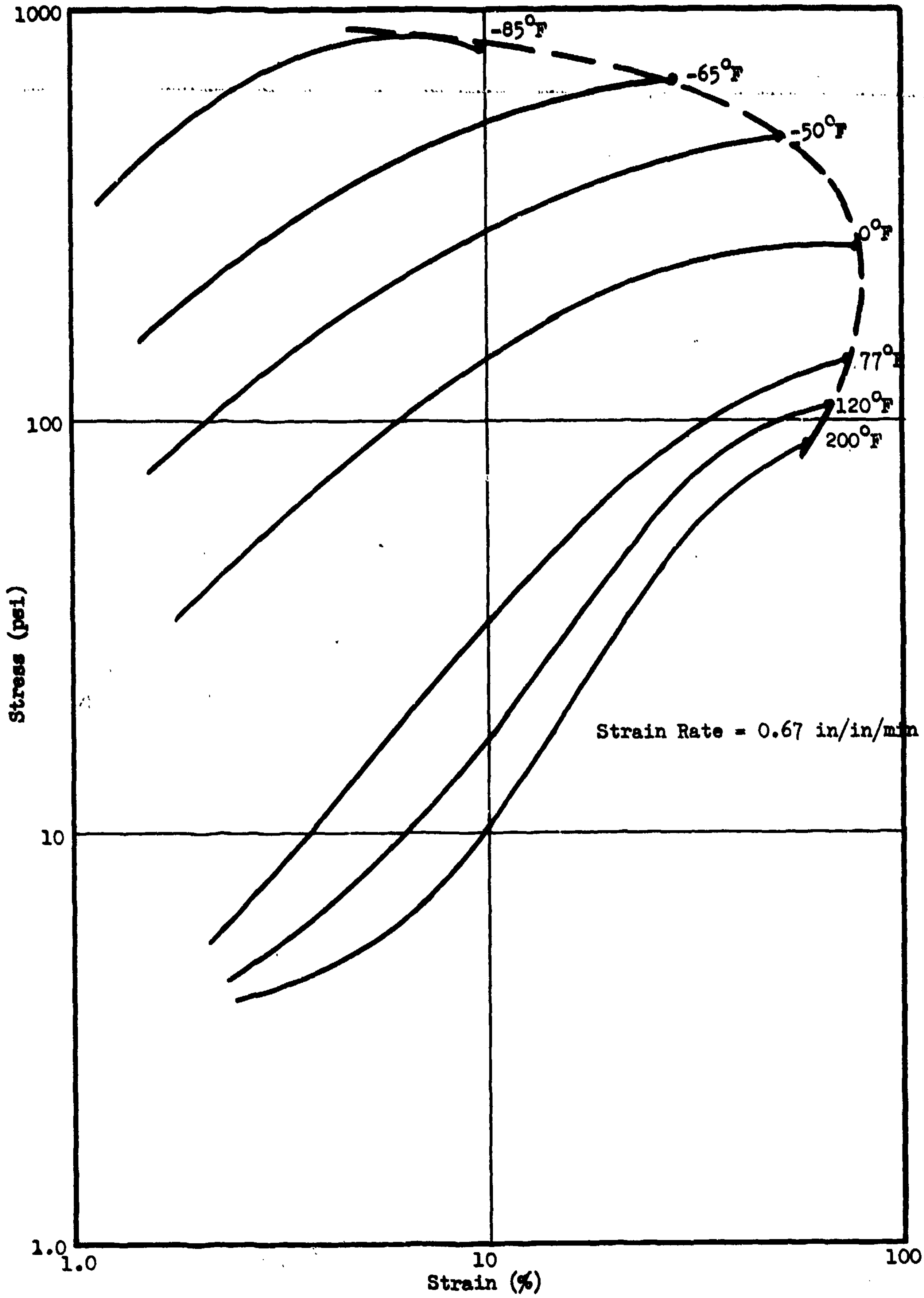

Fig. 11 Stress-Strain Response as a Function of Temperature. 0064-61E Propellant.

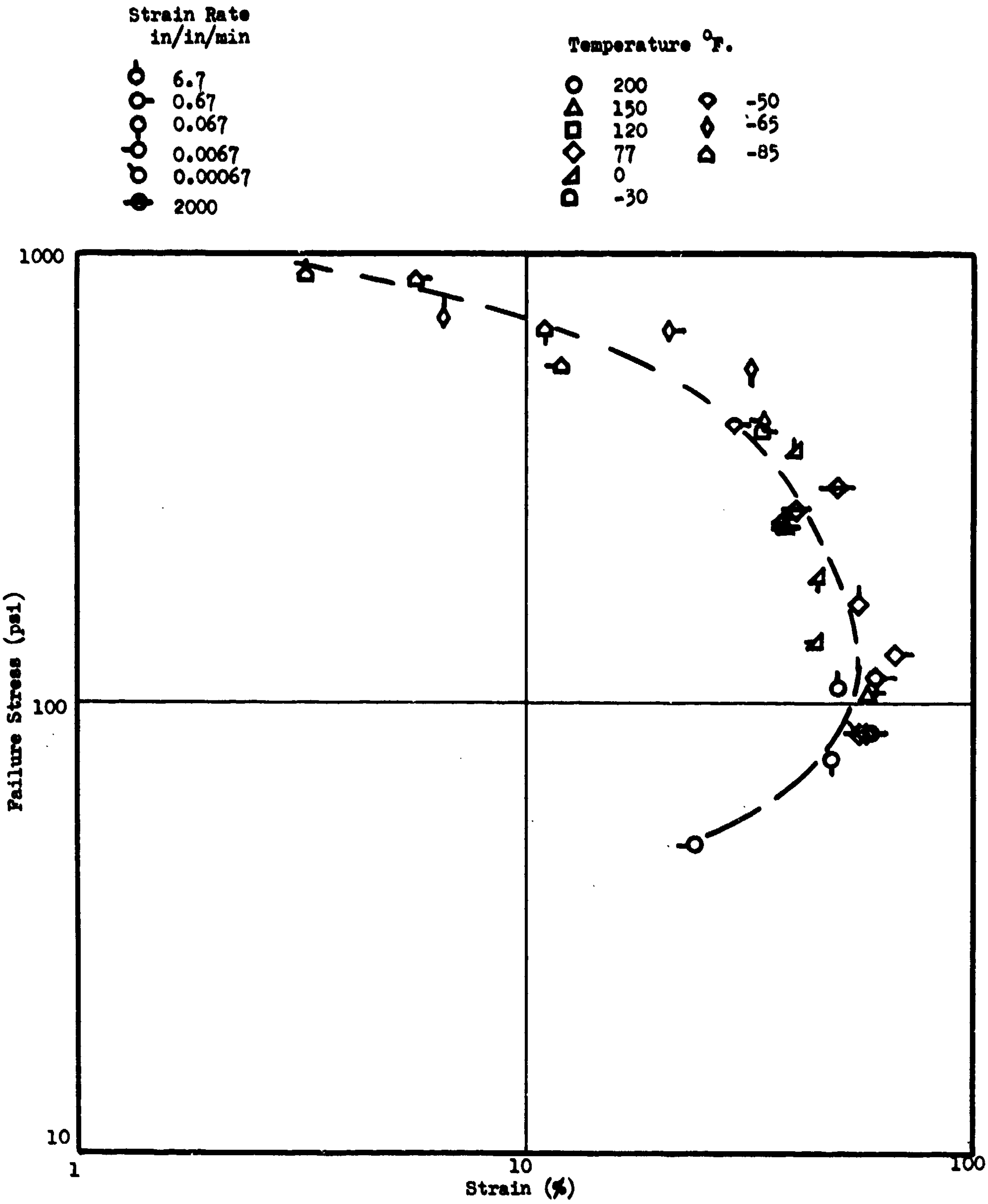

Fig. 12 Stress Versus Strain Failure Envelope. 0064-61E Propellant.

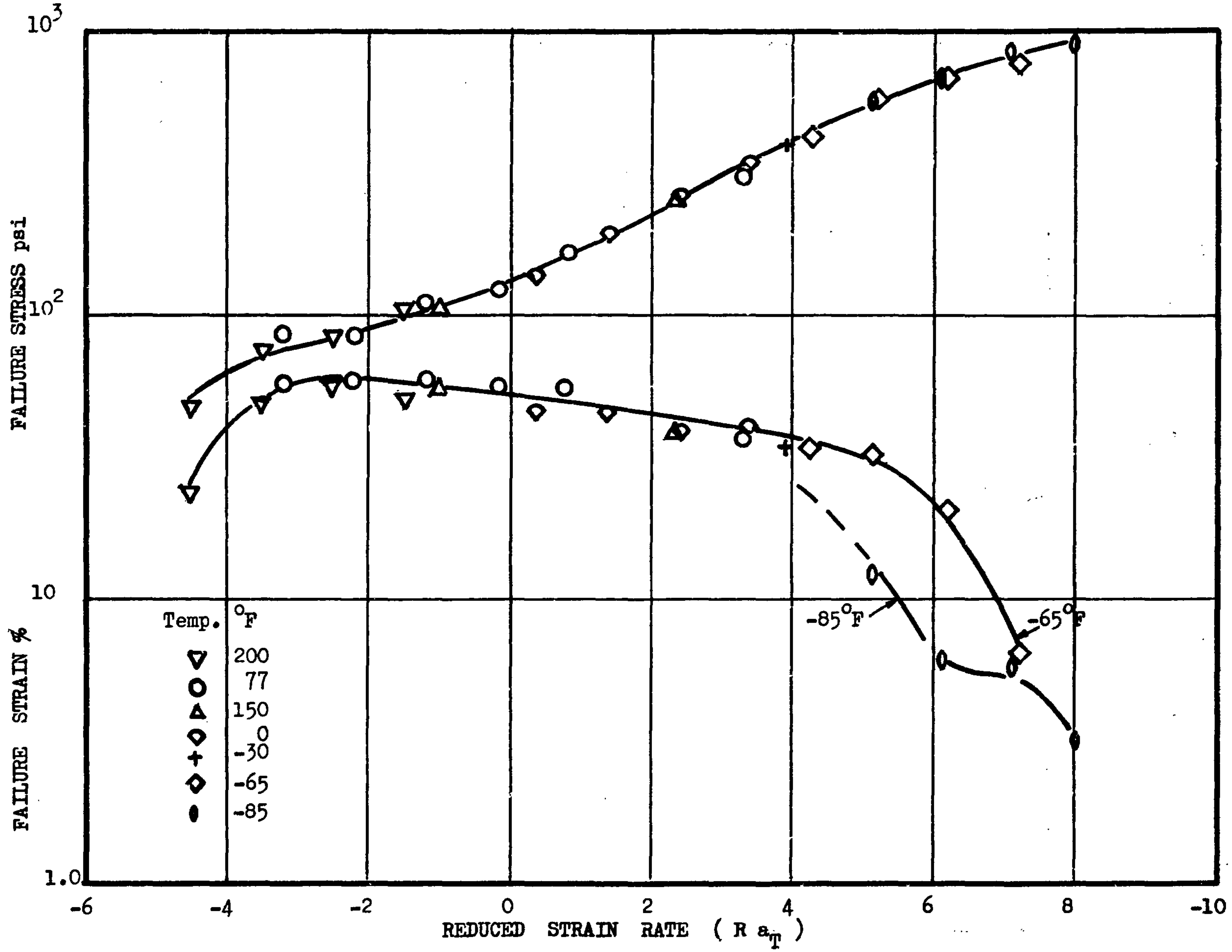

Figure 13 Failure Stress and Strain versus Reduced Strain Rate
0064-61E Propellant

LOW AMPLITUDE SHOCK INITIATION OF BURNING IN HIGH EXPLOSIVES

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INTRODUCTION

It is in the region between burning and detonation that conditions causing most accidents with high explosives occur. Ordinary burning is relatively easy to initiate, occurring more often than detonation. Obviously a vigorous sub-detonation reaction can be very dangerous. The extent to which burning will spread and the vigor of its growth is governed by the chemical nature of the charge, how it is prepared, the charge geometry, size, and boundary conditions.

Most accidents with high explosives involving impact occur in the velocity range of a few meters per second to a few hundred meters per second. This represents a range of pressures generated in the explosive of a few atmospheres to several kilobars. The duration of the pressure pulse may last several milliseconds, as in the drop of a large charge, to several microseconds as in a small fragment impact against a charge. Friction undoubtedly is a dominant cause of reaction in many weak-impact accidents. At impact velocities of, perhaps, 100 m/sec or more, other mechanisms causing reaction can become important.

It is well known that an explosive may seem to be quite "sensitive" under one set of conditions and relatively insensitive

under another. Also, an explosive showing high insensitivity to detonation by shock compression (high detonation threshold) may have a relatively low burning threshold. In some sensitivity tests the explosive charge is crushed and pinched, as in the Susan[1] and similar tests[1,2]. Such tests yield much valuable information applicable to explosive safety. Undoubtedly, the conditions found in these tests are more like those that develop in many actual mishaps than those present in simple shock-compression situations. However, to explain fully the events that occur, the important parameters should be isolated or, at least, reduced in number.

In our low-pressure initiation studies we have tried to limit ourselves to experimental conditions in which deliberate crushing of the explosive between metal components and rubbing over a rough surface are avoided. We are looking for relatively simple systems that yield threshold-for-burning data with more easily defined parameters. The results then could be correlated with those obtained in other, more complicated, tests such as those referred to above. This could lead to a clearer understanding of the role of compression, rubbing, shear, and secondary impact in the initiation of high explosives.

Ideally, we would like to use experimental charge systems that cover the range of shock durations from several microseconds to several milliseconds. However, we have had to restrict the upper weight limit of the explosive under test to one or two pounds. With this weight restriction it is difficult to obtain a pressure duration in the acceptor of more than 50 μsec. In

spite of this, two types of experimental systems used in this study give sufficient differences in shock duration to indicate the effect of the magnitude of duration on the threshold of burning. These are the modified gap test and the underwater experimental system.

In the modified gap test the duration of shock is 1-2 μsec. This value is obtained from studies made of the standard card-gap test which uses the same donor-gap system[3]. Typically, using this experimental arrangement, the peak entering pressure, just causing chemical reaction in most common high explosives, is 7-25 kbar[4]. In the underwater system, the duration, defined as one time constant, $\theta=1/e$, is calculated to be 20-40 usec[5]. The peak threshold pressure for producing burning is 308 kbar[6]. Thus, a typical common high explosive shocked by a pressure pulse, decaying in about a microsecond, requires three times the peak amplitude to produce burning as one shocked with a duration lasting an order of magnitude longer. In making this comparison the degree of curvature of the shock front is assumed not to have any great effect on the results, although some curvature effect undoubtedly is present.

The aim of this paper is to present some typical results, obtained with the two types of experiment, with the hope that they will find usefulness in testing and evaluating high explosives for performance and safety. Some of the material has been published, some is new. Most of the experimental details can be found in References 4 and 6. More space is devoted to results obtained from the modified gap test than to those obtained from underwater experiments, since there

are more modified gap-test data to draw upon. However, as already mentioned, the corresponding threshold for burning, P_b, for the underwater system is readily determined from the modified gap-test data. On the other hand, a simple relation between the threshold for detonation, P_s, in the two experiments has not been determined. This is due largely to the fact that the build-up to detonation is much more easily influenced by environment and geometry than is the mere production of burning.

EXPERIMENTS AND DISCUSSION

The Modified Gap Test

The modified gap test, Fig 1(B), uses the same donor-gap system employed in the NOL standardized gap test[7], Fig 1(A). In the latter test the acceptor is 36.5 mm diam, 139.7 mm long, and confined in a steel tube with a 5.6-mm wall thickness. The diameter of the acceptor in the modified gap experiments has been increased to 50.8 mm, and the acceptor is left unconfined. The acceptor length is 12.7 mm, except when studying the effect of acceptor length or determining the "run distance" to full detonation.

The presence of chemical reaction is detected by end-on and side-on surveillance of the acceptor by a high-speed framing camera. Burning is directly evidenced by the break-out of gaseous products. The time for the break-out to occur is measured as a function of entering shock pressure. A plot of the data can be extrapolated to give the threshold pressure required to initiate burning. It is possible to have internal burning such that

gaseous products are not visible. The chemical reaction increases the surface velocity above that observed for a comparable shocked inert material. Consequently the free-surface velocity, U_a, also is measured as a function of the peak entering shock presure, P_e.

The value of U_a is the instantaneous velocity of the acceptor surface along its extended axis after it has moved 50 mm. The velocity in this distance becomes fairly constant. This includes cases where the acceptor surface is completely converted to gas or even when detonation occurs and a luminous shock front is present. For all high explosives tested, it has been determined that when U_a reaches about 4.5 mm/usec, detonation is occurring. On some records, near threshold pressures, a small region of detonation occurs and a small disk of luminous air shock appears in the central region of the flat surface of the acceptor. This pin-points the value of P_s.

Typically, the surface velocity vs pressure (U_a vs P_e) curve shows an abrupt change in slope at the threshold pressure for burning, P_b. This results in a very sensitive means of detecting reaction. It is estimated that the effects from as little as 0.1 g of reacted material can be detected by this method.

Examples of the U_a vs P_e curves are shown in Fig 2 for tetryl (density = 1.65 g/cm³), TNT (1.62), and TATB (1.82), all pressed. [The particle size of all pressed explosives referred to in this paper is 70-100 mesh, i.e. 149-210 μ.] The thresholds of burning, P_b, are 13, 22, and 67 kbar respectively. The

corresponding thresholds for detonation, P_s, are 18, 51, and 81 kbar. These three pure explosives roughly typify the range of sensitivity to be expected in a main charge of high explosive.

The U_a vs P_e curve for a pressed mixture of high explosive, 60/40 cyclotol (density = 1.70 g/cm³) is given in Fig 3. Also shown is the curve for a propellant, EJC (density = 1.80³g/cm). The thresholds for burning are 13 kbar in the cyclotol and 31 kbar in the propellant. The thresholds for detonation are 27 and 44 kbar, respectively. Note the strong similarity of the shape of the curves, also that of TATB, Fig 2. The results shown in Figs 2 and 3 are discussed more fully in the next section.

Shape of the U_a vs P_e Curve.

The determination of P_b and P_s is not sufficient to describe adequately the sensitivity of the explosive to burning and to full detonation. The general shape of the U_a vs P_e curve is indicative of this. For example, in the modified gap-test experiments, the free surface velocity of pressed 60/40 cyclotol, Fig 3, rises sharply at P_e = 13 kbar and then increases gradually from 1.3 to 2.0 mm/μsec between 15 and 25 kbar. A pressure of at least 25 kbar is required to produce full detonation in this geometry, using a 12.7-mm thick acceptor. The region of low slope between 15 and 25 kbar may indicate a condition that would support the propagation of a reaction at a more or less constant velocity, but considerably below that of normal detonation. Apparently it is possible for two different explosives to have the same values of P_b and P_s, one with and one without a prominent U_a vs P_e inflection.

[The U_a vs P_e curves are influenced somewhat by the way the velocity analysis is made, see Reference 4. However, the general shape would not be expected to change significantly with minor changes in analysis.] In any case, the shape of the U_a vs P_e curve is indicative of the ease in which full detonation is reached. The curve for tetryl indicates a relatively low threshold for burning, P_e = 13 kbar (<5 kbar predicted for the underwater tests). It also shows a pronounced tendency to go into detonation, i.e. a steep slope with no significant inflection. The curve for TATB shows a very high threshold for burning and some "hesitation" to go into detonation, as evidenced by the inflection. However, at above 80 kbar the transition to full detonation is abrupt. The curve for pressed TNT is greatly different from the others. The threshold for burning is moderately low and the threshold for detonation is relatively high. The most striking feature, though, is the relatively constant slope of the curve, i.e. no prominent inflection. This is indicative of an inherent "reluctance" for the reaction to develop into full detonation. It does not approach the threshold for detonation with the abruptness of the other explosives.

It should be emphasized that the charge geometry, density, and particle size have a great deal to do with the growth to detonation. The examples given were all pressed from bulk explosives having comparable particle size. The density variation from one explosive to another, expressed in per cent of maximum theoretical density, was 94 to 98% TMD. This, of course, affects

the comparative results somewhat. In addition, the particle size could have been altered by the pressing process. However, the results given here probably are adequate for assigning reasonable comparative (mechanical shock) sensitivities to the several explosives.

Effect of Varying Charge Length

Once a vigorous reaction has been started in a thin acceptor it may grow to detonation if the length of the acceptor is increased. On the other hand, it may die out completely. Another possibility is that it may propagate at sub-detonation velocity for an indefinite run distance. The possibilities can be illustrated, Fig 4, using pressed TNT (density = 1.62 g/cm³) in the modified gap-test arrangement. At an entering pressure of 31 kbar the amount of reaction, indicated by the free-surface velocity of the acceptor, U_a, increases with length up to about 0.75 inch (19mm) and then falls off. If the material had shown no reaction, the curve would have followed the corresponding lower (thin line) curve, labeled U_a^*. At P_e = 37 kbar, using interpolated points, it also falls off. At P_e = 41 kbar it reaches detonation in about 0.75 inch (19mm). At P_e = 46 and 52 kbar, the run distances to detonation are indicated by the intersection of the curves with the horizontal line at 4.5 mm/μsec. These are 15 mm and 13 mm, respectively. In support of this, detonation is observed to break out on the sides of the charge at these distances, within experimental error, i.e. 12-15 mm. Somewhere between 37 and 41 kbar a reaction might take place which propagates at a more or less constant velocity. This would

occur if the energy losses became balanced with the energy released by the chemical reaction within the limits of the wave structure. Experimentally attaining this condition might be difficult or impossible with the particular high density, pressed TNT used in these experiments.

A similar series was made of <u>cast</u> TNT acceptors, all cut from the same 15-inch long explosive casting, Fig 5. The transition to detonation was not obtained for the 77 kbar curve because of an insufficient number of acceptors obtainable from the particular casting. (Sensitivities can change from casting to casting, even though the same explosive lot is used.) However, it is reasonably certain by the trend of the data that detonation would have been reached in the 1.0- or 2.0-inch lengths. Therefore, the pressure required for an indefinite run distance of "low velocity detonation" probably lies between 63 and 77 kbar.

Indefinite Run Distance to Detonation

Another way to determine the "indefinite run" value of pressure is to measure the distance to break-out of detonation as a function of P_e. The acceptors, of course, are made appropriately long. If we plot the reciprocal of the run-to-detonation distance, X_ℓ, against P_e on a semi-log scale, an approximately straight-line relation is obtained. Examples are shown in Fig 6 for cast Composition B, using two different sources of explosives, Lot A and Lot B. One assumes that when the run distance to detonation has reached two charge diameters (102 mm),

the threshold value of P_e is attained for all practical purposes. This is represented by the horizontal line at $100/X_\ell = 0.98$.

The longest run distance that we have recorded in a high density, high explosive is 2.1 charge diameters. This occurred for cast 25/75 cyclotol (3% carbon black added, density = 1.66 g/cm^3, P_e = 42 kbar). By a lucky chance we caught the break-out of full detonation just before the end of the 5.0-inch long charge was reached. This is shown in Fig 7(A). Note that no backward detonation (retonation) is evident. The wedge shape of the region that has detonated, is due to the action of the focal plane shutter in the framing camera used in all these experiments. Time is progressing from right to left. A detailed description of the camera is given in Reference 7.

Retonation

The ease with which an explosive retonates is an indication of the ease with which detonation can be produced. For a given explosive the occurrence of retonation depends on the way the charge is prepared, the charge diameter, the shape of the shock front, the peak pressure, and the duration of the pressure pulse[8]. An interesting example of a marginal retonation is shown in Fig. 7(B) for cast Composition B (P_e = 28 kbar). Here retonation breaks out in several places along the backward-moving shock front. This is the only example of a marginal retonation that we have obtained. Compare this with the example of a fast-acting retonation in Fig. 7(C) or with the example in Fig. 7(A) having no detectable retonation.

The Underwater Experiments

In the underwater explosive system, Fig 8, the donor charge is a 82-mm diam cast pentolite sphere nominally weighing a pound. For most experiments the acceptors are the same size (2.0-inch diam, 0.5-inch thick) as those used in the modified gap test. Again, the observations are made with a high-speed framing camera. Diffuse reflected backlighting is obtained by an argon flashlamp which illuminates a white cardboard in back of the tank.

The peak pressure (stress), P_e, entering an acceptor is changed by altering its distance, X, from the spherical donor, where X is the distance from the surface of the donor to the donor-facing surface of the acceptor. The peak pressure in water at a given distance is obtained from the corresponding instantaneous shock velocity. The latter is determined by differentiating along an X-time curve drawn from data obtained from framing camera sequences. The method of conversion from the pressure in water to the transmitted stress in the acceptor is described in Reference 9.

Chemical reaction is detected by observing the expansion of the acceptor after being struck by the shock. The most vigorous burning is at the surface facing the donor. No reaction is occurring around the perimeter of the opposite (initially flat) surface. This is proven by frontlighting as well as backlighting the acceptor. Typically, at pressures near the threshold, the acceptor will show no gross expansion for a relatively long time, then expansion will start suddenly. This induction time, i.e. the period for reaction to become apparent, can be as much as

35 μsec or more. If the thickness, S, of the shocked acceptor is plotted as a function of time, t, after being struck by the shock, a fairly constant rate of expansion (dS/dt = const) is obtained. Examples of dS/dt vs P_e curves are shown in Fig 9 for pentolite, 60/40 cyclotol, and TNT. As previously stated, the threshold for burning in the underwater experiments is about one-third of that found in the modified gap test.

Threshold for Detonation in Water

The effect of length on detonation threshold in the underwater experiment is much more difficult to detect than in th modified gap test. This is due largely to optical distortion by shock waves in water. However, we were able to determine the run distances to detonation in some instances. For pressed 60/40 cyclotol a run distance, X_ℓ, of 67 mm was obtained. In Fig 10 the sequence shows the shock entering the acceptor (P_e = 13.9 kbar) and accelerating until break-out of detonation occurs. Because the run distance is fairly long, the threshold pressure must be only slightly lower, say 13.5 kbar. Note that retonation is occurring.

SUMMARY AND CONCLUSION

Two types of experiments are discussed in which high explosives are subjected to shocks of low to moderate amplitude, th modified gap test and the underwater system. The duration of the pressure pulse is 1-2 μsec in the former and 20-40 usec in the latter. Observations are made with a high-speed framing camera. The underwater thresholds for burning are one-third of

those obtained in the modified gap experiments. No simple relationship has been found between the thresholds of detonation found in the two systems, although they are definitely lower in the underwater experiment.

The modified gap test is a sensitive method for indicating the degree of chemical reaction. It may be possible to refine this type of test to accurately termine the intensity and extent of chemical reaction. The underwater system is not as sensitive in detecting reaction as the modified gap test and is not as easily controlled. However, it is of importance in studying the effect of shock duration.

In both tests the threshold of burning, P_b, is more easily pinpointed than is the threshold of detonation, P_s. The latter is greatly dependent on the length of charge and its surroundings. The threshold of burning, under identical shock impulse, seems relatively unaffected by these variations. Knowing the conditions under which detonation will develop, of course, is important, therefore, the determination of P_s is important.

Results using TNT show that the development of a vigorous reaction in a short acceptor does not guarantee the development of detonation in a long acceptor. Unless the input stress is above a certain critical value, the reaction will die out. At the critical value the reaction may propagate at a more or less constant velocity for an indefinite distance, but at well below normal detonation velocity. The necessary condition of energy balance may not be obtained practically for the high density TNT used in the example. This possibility is indicated by the shape

of the U_a vs P_e curve, i.e. no significant inflection is seen. [This does not mean that TNT is incapable of supporting a low velocity reaction at a fairly constant velocity. Indeed, such a velocity has been shown to exist in pressed TNT, but at a much lower density and with larger particle size[10].] The U_a vs P_e curves for 60/40 cyclotol, EJC, and TATB all indicate the possibility that the low "constant" velocity reaction can be generated in these explosives.

Most common high explosives exhibit a threshold of burning of 3-8 kbar in the underwater experiments. These stresses are comparable to those obtained in the Susan and similar tests at impacts against steel of 80-180 m/sec. Thus, in many of the Susan-type experiments there exists some internal burning produced by shock compression before extensive extrusion and pinching of the explosive occurs. Undoubtedly, in many cases the effects from friction and explosive extrusion mask out the effects of simple compression. However, it is shown by this study that the susceptibility of an explosive to burn under simple shock compression of low amplitude also is a factor of importance in performance and safety.

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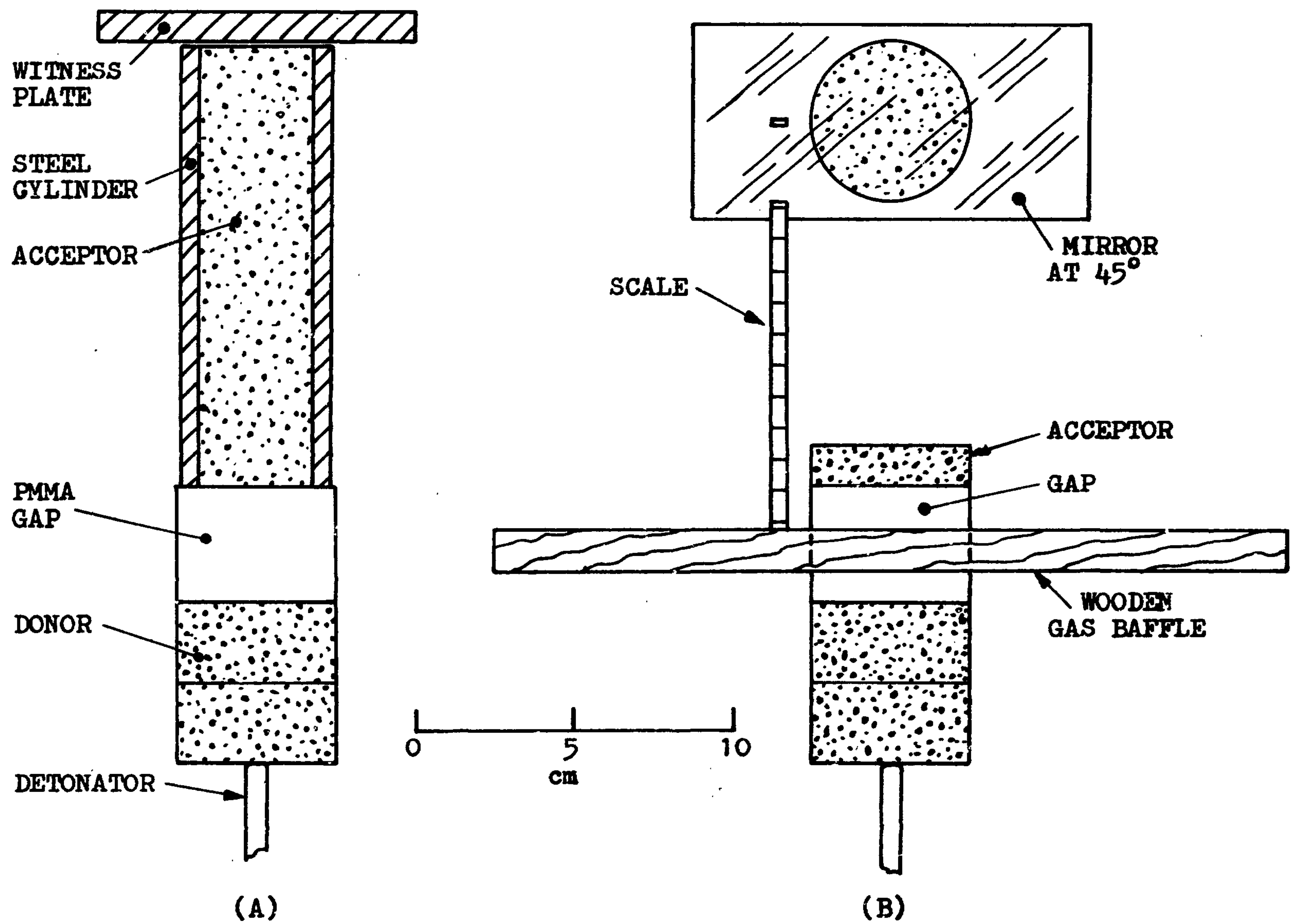

FIG. 1. (A) THE NOL STANDARDIZED GAP TEST; (B) THE MODIFIED GAP TEST.

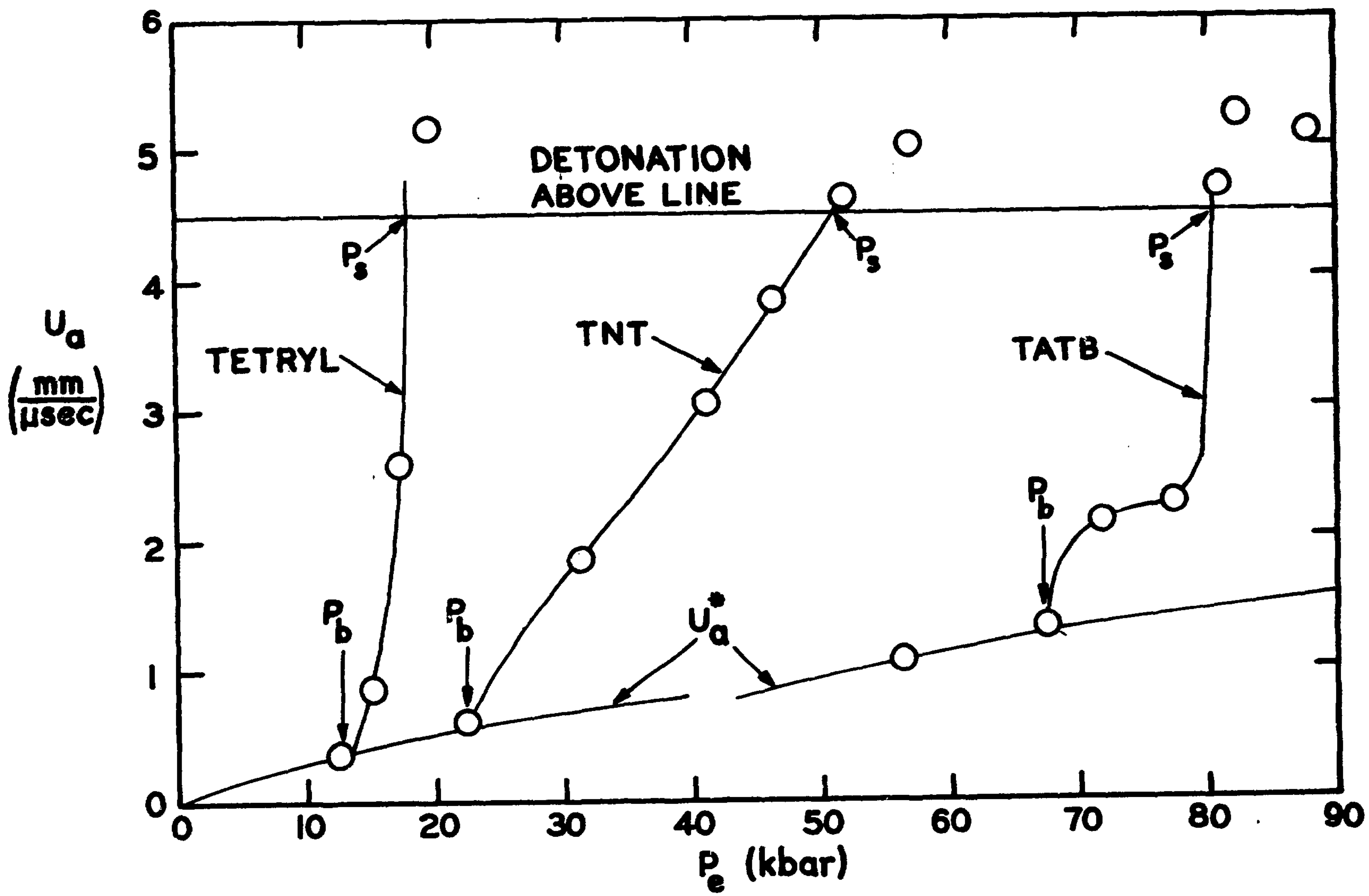

FIG 2 The free-surface velocity of the acceptor, U_a, as a function of the peak entering pressure, P_e, for tetryl, TNT, and TATB (all pressed). The lines labeled U_a^* are calculated for the unreacted material. The thresholds for burning are indicated by P_b and the thresholds for detonation by P_s.

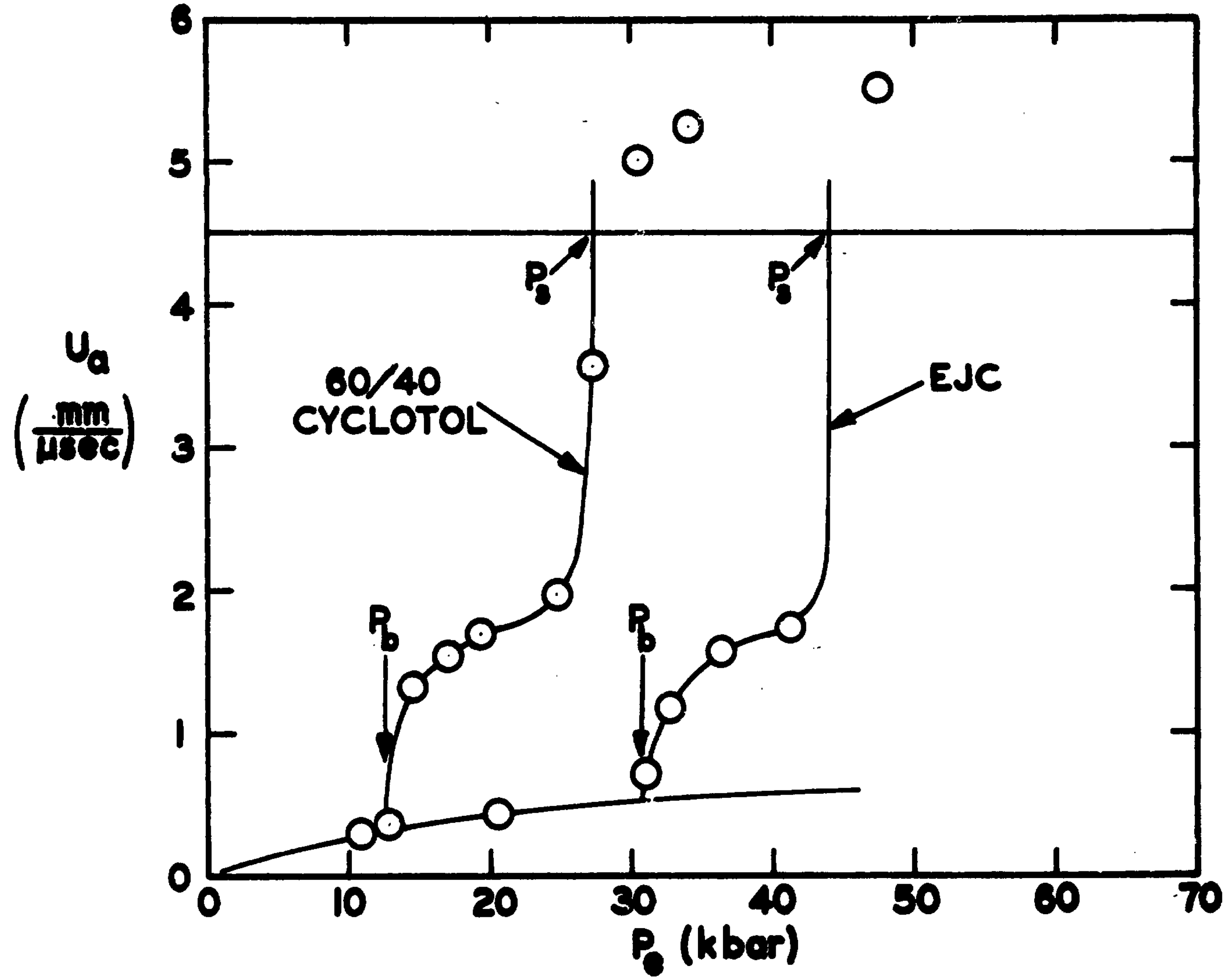

FIG 3 The free-surface velocity, U_a, as a function of the peak entering pressure, P_e, for 60/40 cyclotol and the double base propellant EJC.

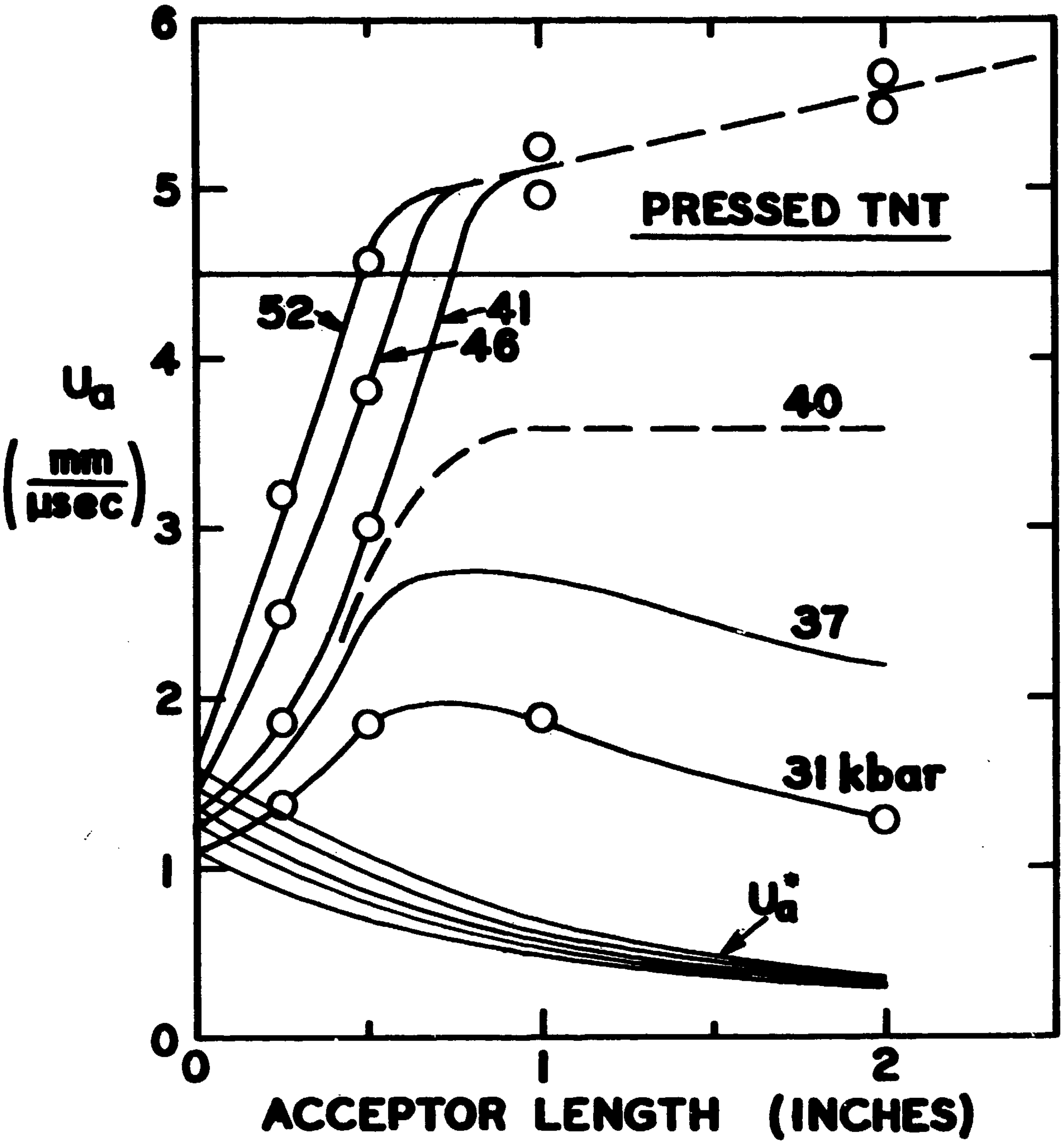

FIG 4 The free-surface velocity, U_a, as a function of the acceptor length for pressed TNT (density = 1.62 g/cm^3) at various initial pressures. The curves near the bottom are those drawn from the calculated (unreactive) values of U_a.

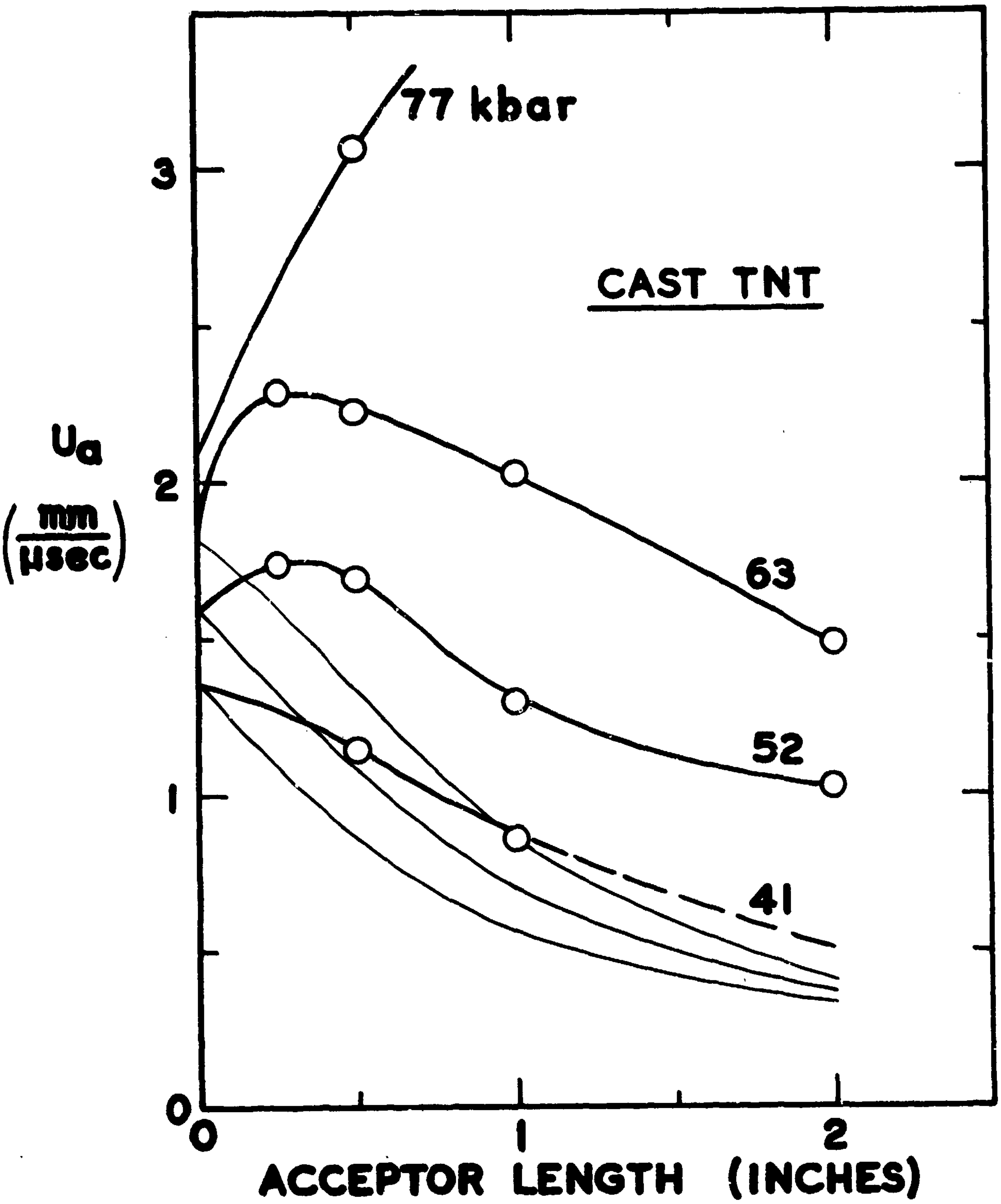

FIG 5 The free-surface velocity, U_a, as a function of the acceptor length for cast TNT (density - 1.62 g/cm^3) at various initial pressures.

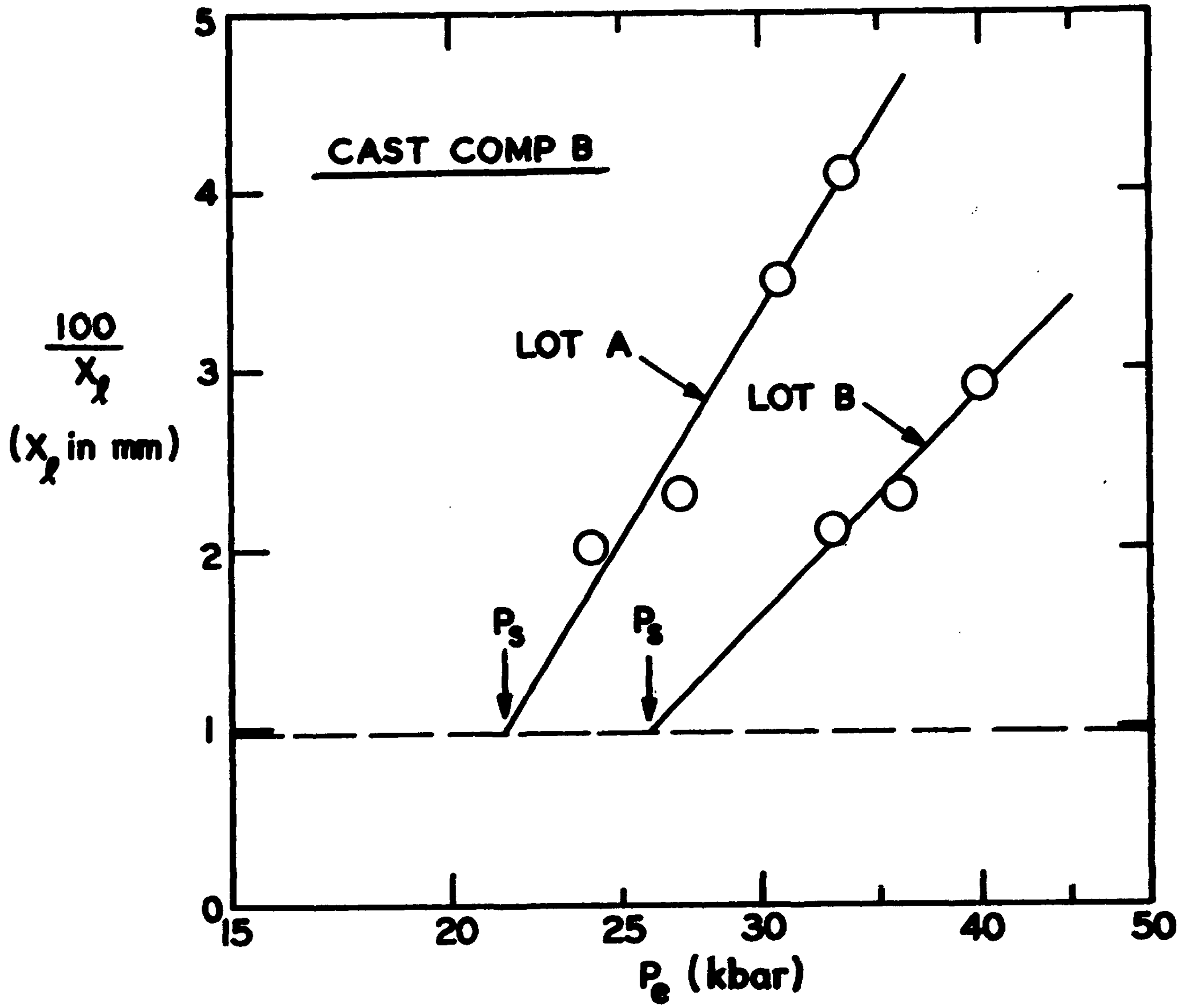

FIG 6 The reciprocal of the run distance to detonation, X_ℓ, (x100) as a function of P_e for two sources of cast Composition B. The thresholds for detonation are indicated by P_s.

A B C

FIG 7 Breakout of detonation: (A) No retonation; (B) Marginal retonation; (C) Full retonation.

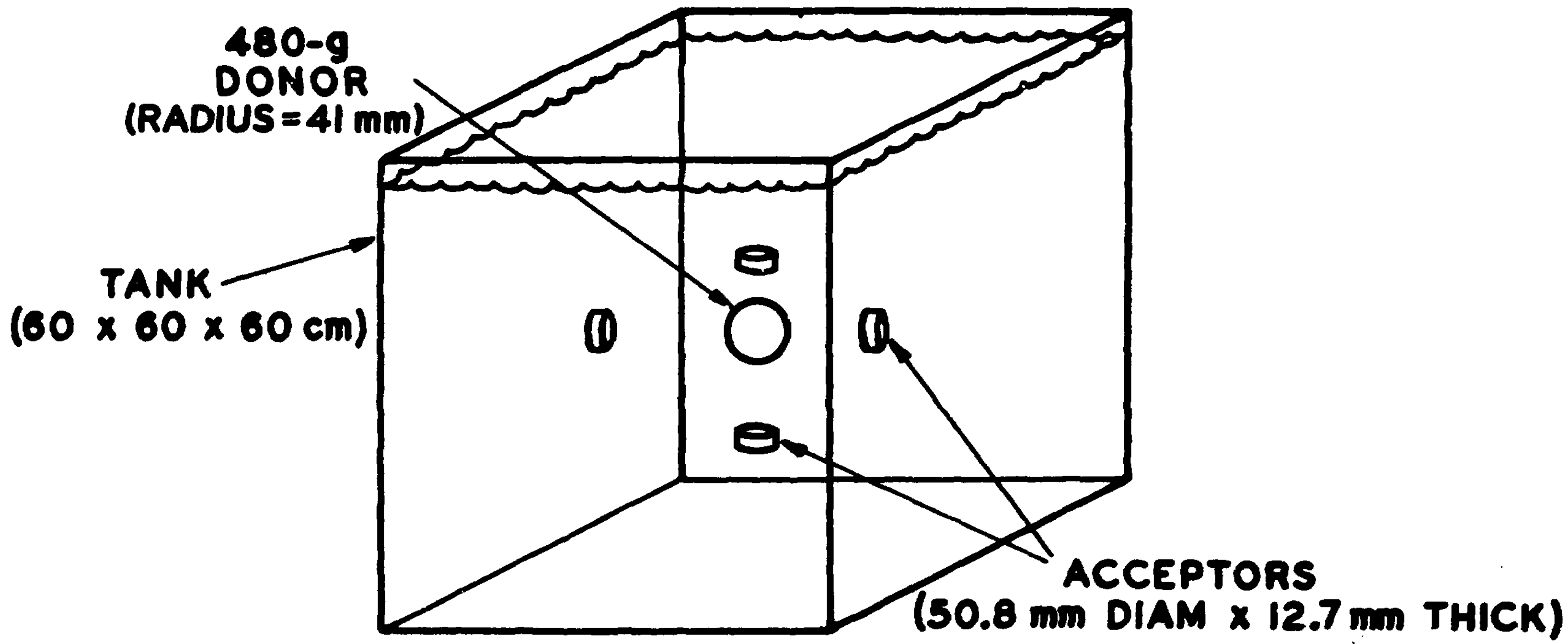

FIG 8 The underwater system.

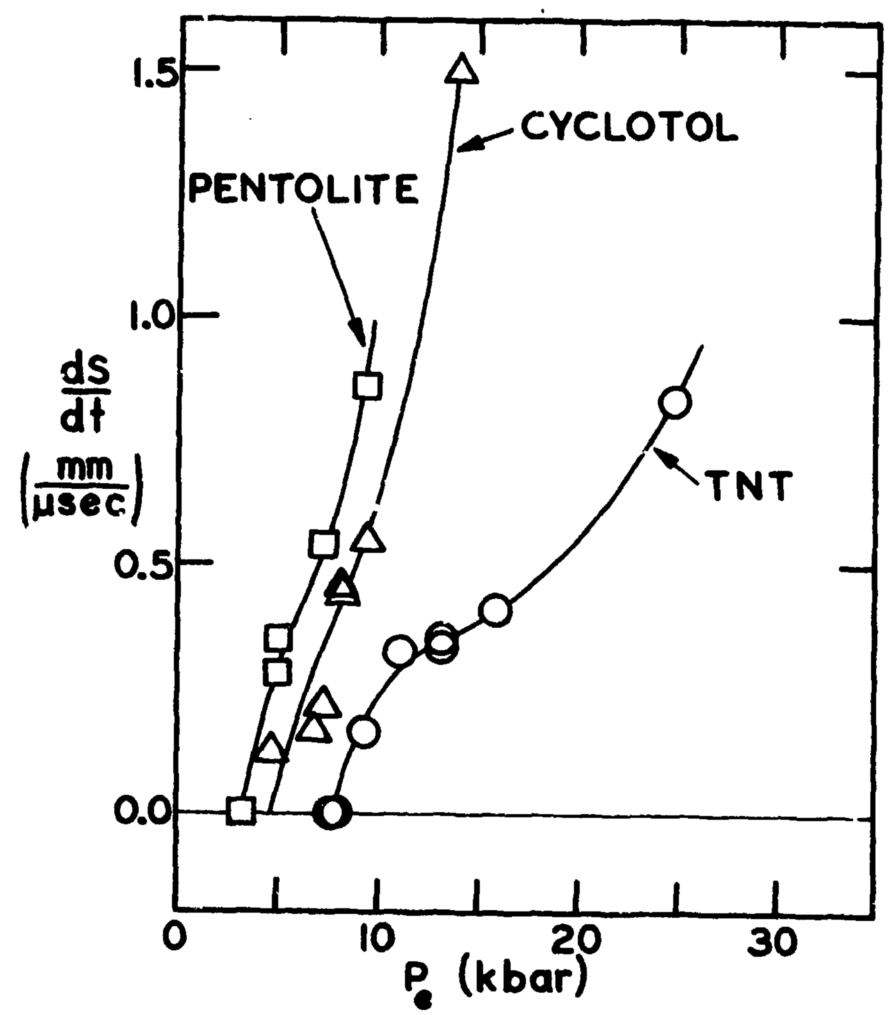

FIG 9 Rate of expansion (dS/dt) as a function of the entering pressure (P_e) for Pentolite, 60/40 Cyclotol, and TNT

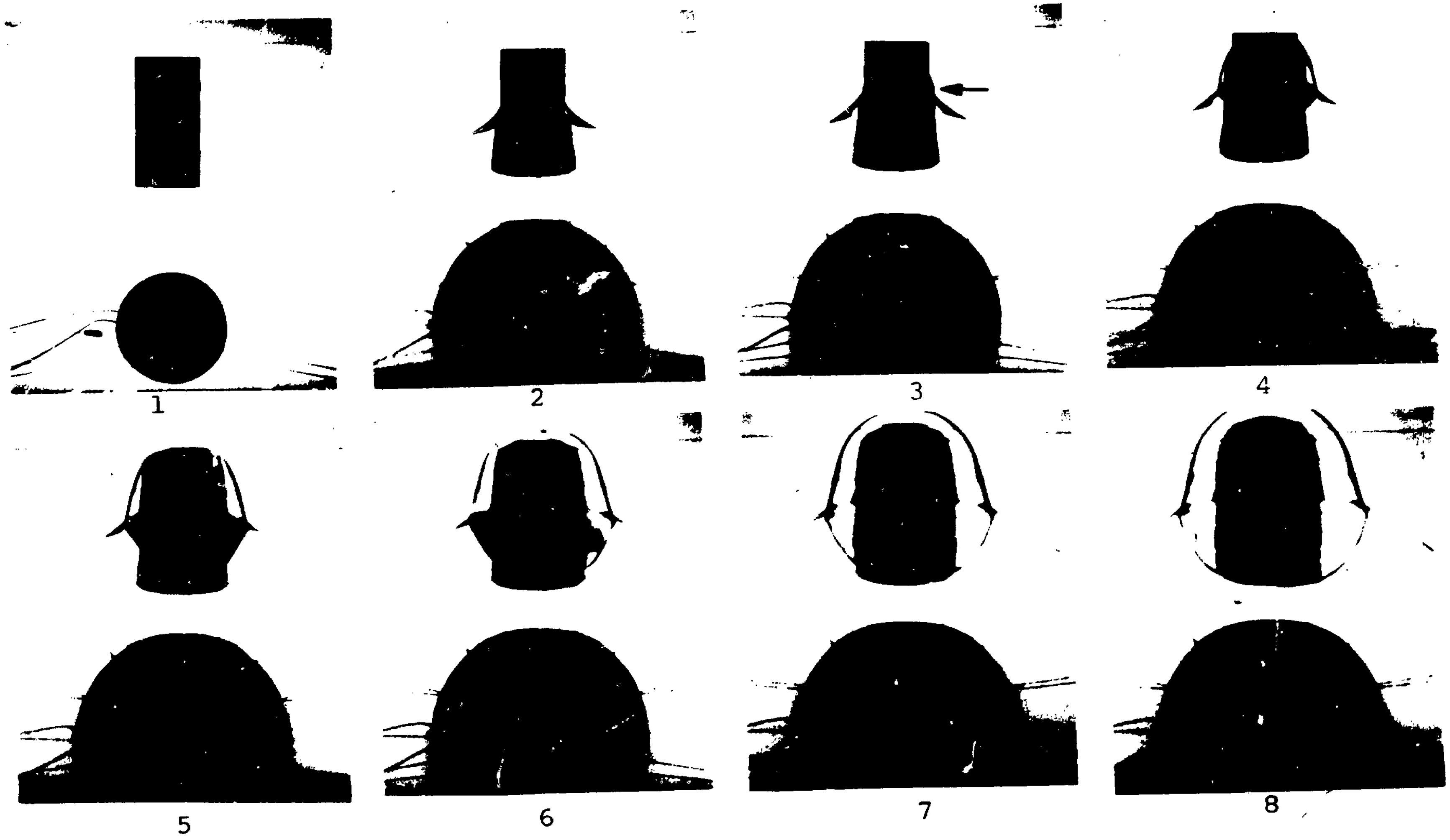

FIG 10 Underwater detonation and retonation in a 102-mm long cylinder of pressed 60/40 Cyclotol. Breakout first appears in 3rd frame, at arrow, 35 mm from end of acceptor. Entering pressure is 13.9 kbar. The 2nd frame is about 45 microsec after donor initiation. Time between remaining frames is 2.2 microsec. Focal plane shutter sweep is from right to left.

LOW VELOCITY DETONATIONS*

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I INTRODUCTION

It is the purpose of this paper to review the results of our studies on low velocity detonations and to make some recommendations for the safe handling of explosive and monopropellant liquids. To place these results and recommendations in a broader perspective, we will also review some limitations of shock sensitivity testing.

Sensitivity is a quantitative expression of the ease with which instantaneous decomposition of an explosive can be initiated. However, no single parameter or number adequately describes the response to all kinds of initiating stimuli, and thus there are different kinds of sensitivity, e.g., thermal, static, friction, impact, shock, etc. Of these, all but one express only the ease of initiation; shock sensitivity expresses ease of initiating a reaction which propagates as a detonation. At least that is the hope of those who perform shock sensitivity tests, and it is to the limitations of that hope that the balance of this paper is directed.

II SHOCK SENSITIVITY TESTING

The manner in which shock sensitivity is tested need not be described here, for it is done well elsewhere.[1] Results are interpreted as a measure

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of the shock strength required to initiate detonation in an acceptor. Accordingly, two basic requirements are presumably met by the testing procedure: the shock imposed upon the acceptor must be measurable, and stable detonation must be detectable. Furthermore, it is generally assumed that the results are not significantly affected by either the acceptor container or the detonation detector. Experience has shown that these requirements and assumptions are generally satisfied and this accounts for the reliability of the test results. However, instances have been reported in which the measurable shock from the donor is so modified and strengthened by interaction with the container walls that the effective shock strength is no longer known.[2] Also the usual detonation detectors are not sensitive to those detonations which propagate at velocities much lower than those computed from the hydrodynamic conservation laws.[3] Thus non-Chapman-Jouget detonations may be initiated but not detected. Because these low velocity detonations (LVD) are much more easily initiated than their normal counterpart[4] and are as dangerous, an understanding or a cataloging of their causes and reliable methods for their detection are essential to safe operating procedures.

III LOW VELOCITY DETONATIONS

A. Theory

Low velocity detonations propagate at a velocity only slightly supersonic with regard to the unreacted material. Characteristically, they are very easily initiated but are very difficult to distinguish from conventional detonations.

Two models have been offered. These are described elsewhere and for brevity will not be discussed in detail here. One is called the cavitation model;[5] the other, proposed by the present authors and our associates, is the Mach zone model.[6] Both require that the detonating liquid be in a container of higher sound speed than itself. Heuristically, both predict that LVD sensitivity increases as the sound speed of the container increases. Of the two models, only the Mach zone model requires that LVD sensitivity in circular cylinders be markedly greater than for the same liquid in rectangular confinement. It also relates LVD sensitivity to decomposition kinetics. By and large the Mach zone model is supported by experimental evidence, but additional causes of LVD have also been observed.

B. Experiments

1. Test for LVD

Conventional gap tests do not detect LVD. Ionization probes require temperatures too high to be attained in LVD, and the shock pressures prevailing in the LVD wave are either so low or occur over so small a region that the 3/8 inch thick steel witness plates used in gap tests sustain no detectable damage.[3] Pressure-sensitive detectors immersed in the charge are not useful because they may affect initiation.[3]

We have therefore developed a special technique for observing LVD. Figure 1 shows the apparatus used for our LVD gap test. The components are conventional: a tetryl donor, a plastic attenuator (of variable thickness), and a test cup. However, a pressure-sensitive probe is inserted between

the attenuator and the cup and another probe just above the sample. These serve as reliable time-of-arrival gauges, and from an oscilloscopic measurement of the time elapsed between responses of the two probes and from the precisely known cup length, the average velocity of a wave propagating in the liquid can be measured. The stability or constancy of the velocity is assessed by running tests with cups of several different lengths, holding all other parameters constant.

When it is expedient to have a mechanical LVD detector, we use a 1/16 inch thick steel witness plate. Damage to this plate, i.e., a hole caused by the explosion, correlates well with the results from the more precise electronic instrumentation. Nevertheless, with this witness plate as with the probes, only measurements over a range of charge lengths insure that LVD has occurred. Also, as must be apparent, this approach is useful only when high velocity detonation (HVD) does not occur.

2. <u>Effect of Sound Speed</u>

Both the cavitation and the Mach zone models identify the cause of LVD with a sound wave that propagates along the walls of the test cup and sends a precursor "bow wave" into the unreacted liquid. The Mach zone model further relates the temperature increase within the Mach regime to the disparity between the sound speed of the cup and the lower value for the liquid. One would expect, therefore, that the measured sensitivity would increase with this disparity.

Using 1,2-difluoramino propane (1,2 DP) which is known to sustain LVD, tests were run to measure sensitivity in aluminum, brass, and lead

test cups. The results for aluminum and brass (Table I, items a and c) confirm the expectation The results for lead (Table I, item d) are surprising. They show that LVD does occur within this very low sound speed material and would appear to be both inconsistent with and, therefore, fatal to either theory. A photographic examination of the process in lead cups showed otherwise.

Table I

LVD GAP TEST ON 1,2-DIFLUORAMINO PROPANE*
IN VARIOUS CONTAINERS

	Material	Geometry (cm)	Sonic Velocity (mm/μsec)	50% Gap (cm Plexiglas)
(a)	Aluminum	Round I.D. = 1.27 Wall = 0.25	5.1	> 214
(b)	Aluminum	Square I.D. = 1.27 Wall = 0.31	5.1	61 < G < 91
(c)	Brass	Round I.D. = 1.27 Wall = 0.25	3.7	122 < G < 183
(d)	Lead	Round I.D. = 1.27 Wall = 0.64	1.2	$\gtrsim$ 91**

*Sonic velocity ~ 12 mm/μsec

**Propagated at subsonic velocity

The arrangement used for these experiments is shown in Fig. 2. An electronic flash was placed at the focal length of a Fresnel lens to provide a backlight and to give a shadowgraphic picture of a portion of the Plexiglas attenuator and the entire sample tube during the gap test.

Figure 3 contains four frames selected from a twenty-five frame sequence obtained using a gap of 30 cm. The time elapsed from detonation of the tetryl donor pellets is noted on each frame. The initial shock arrived at the Plexiglas-tube interface after 120 μsec. The first frame, 22 μsec later, shows only a slight tube expansion. After 250 μsec there is still no evidence of detonation. However, the tube has greatly expanded at this juncture and is separating from the Plexiglas. The arrow points to the air shock from the donor as it approaches the expanded tube. This air shock arrives at the tube-attenuator interface (267 μsec). Detonation, evident in the next frame (8 μsec later, not shown), travels with an average velocity of $\sim$ 2.0 mm/μsec and arrives at the top of the tube in the last frame shown. (This test was performed without a witness plate; with one, the results are identical). Thus the gap sensitivity results in lead confinement did not invalidate our theory, but they are evidence of still another mechanism for LVD initiation. This new mechanism involves initial shock expansion of the tube and perhaps cavitation of the liquid which ignites only upon the additional energy input of the subsequent donor air shock.

3. Effect of Container Shape

Because of differences in the structure of the converging waves,[7] the Mach region will be at a much higher temperature on the axis of an explosive-containing circular cylinder than in its rectangular counterpart, provided that the container has a significantly higher sound speed than the liquid. In earlier experiments we were unable to initiate LVD in nitromethane/tetranitromethane mixtures confined between flat steel walls, whereas the same mixture in circular tubes was easily initiated

to LVD. More recently we have experimented with 1,2 DP in round and square aluminum tubes. The results (Table I, items a and b) quantitatively confirm the prediction: LVD propagates in both types of container but is far more readily initiated in round tubes.

4. Possible Effect of Witness Plate

Since the results with lead tubing indicated that air shock can be important in the LVD gap test, we performed similar experiments in steel confinement with a gap of 61 cm; the results are shown in Fig. 4. The shock arrives at the tube-attenuator boundary at 248 μsec. The first evidence of detonation occurs 33 μsec later. This detonation travels forward with an average velocity of 1.7 mm/μsec, breaking through the witness plate at 348 μsec. The final frame shows a full scale reaction. There is no tube expansion, and air shocks are not responsible for initiation of LVD. The 33 μsec elapsed from the arrival of the first shock until detonation commences is approximately the time for a shock wave to travel at $\sim$ 5.8 mm/μsec up the steel wall, reflect from the witness plate, and return to the attenuator. To ascertain if the witness plate was influencing the apparent LVD gap sensitivity of 1,2 DP, a test was performed without a witness plate; all other variables were the same. This is shown in Fig. 5. The sequence of events is approximately the same as that shown in Fig. 4, except that LVD did not occur. Physical response but no detonation is seen: the Plexiglas breakup at 286 μsec and the liquid 1,2 DP leaving the tube (403 μsec, arrow). The tube was recovered intact with unreacted 1,2 DP on the walls. We concluded that the presence of a witness plate to reflect the initial shock can lead to initiation of an LVD reaction. We obtained similar results with aluminum tubes.

Correlation of Decomposition Kinetics with Sensitivity

A consequence of the Mach zone hypothesis is that the temperature behind the zone depends largely on the sonic velocity of the confinement. For liquids in cylindrical aluminum or steel, this temperature is approximately 1000°K. It is our hypothesis that this high temperature is responsible for initiating the sequence of reactions culminating in LVD. If the hypothesis applies rigorously, we expect those compounds which decompose at the lowest temperatures to be the most readily initiated to LVD. Dr. David Ross, of our Laboratories, has conducted independent studies of the vapor phase decomposition of the same compounds we have investigated. Though the specific results are classified, there is evidence to support the suggested relation;[8] for example, nitromethane is thermally quite stable and we have not been able to initiate LVD in this liquid.

IV CONCLUSIONS

The implications of our experimental results to safety and handling considerations are obvious. Most important, it must no longer be assumed that absence of conditions conducive to HVD preclude the occurrence of propagating reaction. Also, because little proper testing has been done, absence of information on LVD sensitivity must not be equated to LVD insensitivity. In fact, we have no real evidence that LVD is not a general phenomenon. Therefore, it should be assumed, unless proven otherwise, that a liquid explosive or monopropellant can sustain LVD; also, the occurrence of LVD in solids is not ruled out by theory.

What about the conditions conducive to LVD initiation? Obviously confinement of suspect liquids in circular tubes and/or in materials with high sound speed can be more dangerous than the opposite. The way of caution lies in using rectangular tubes of lead or plastic.

Initiation by air shock is a possibility obviously to be avoided. We can made no concrete suggestions except that baffles, obstructions, or attenuators might be useful. Similarly, initiation by reflection from a witness plate bears a striking resemblance to the "water hammer" phenomenon. Avoidance of this possibility lies in tho following well-known and acceptable practices, e.g., use of properly designed valves--we have little to suggest of practical use along these lines.

Lastly, the apparent relation between gas phase decomposition kinetics and LVD sensitivity means that kinetic factors must be considered in designing safe handling procedures.

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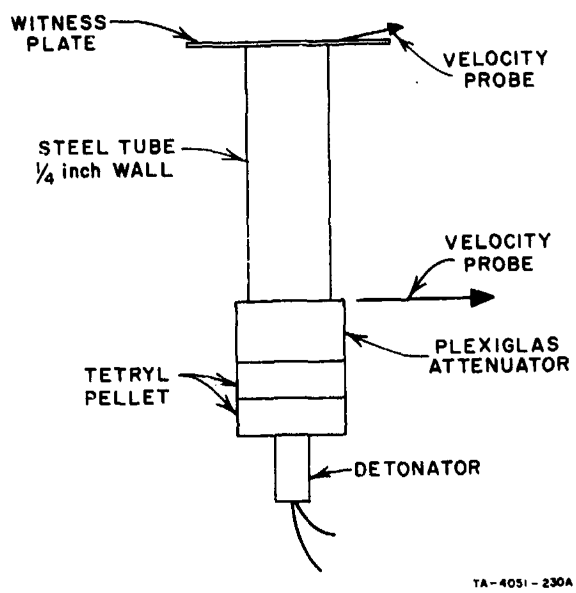

FIG. 1 LVD GAP TEST ARRANGEMENT

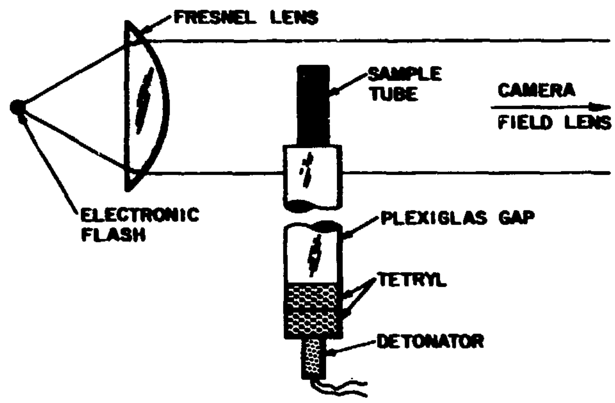

FIG. 2 TEST ARRANGEMENT FOR HIGH SPEED FRAMING PICTURES

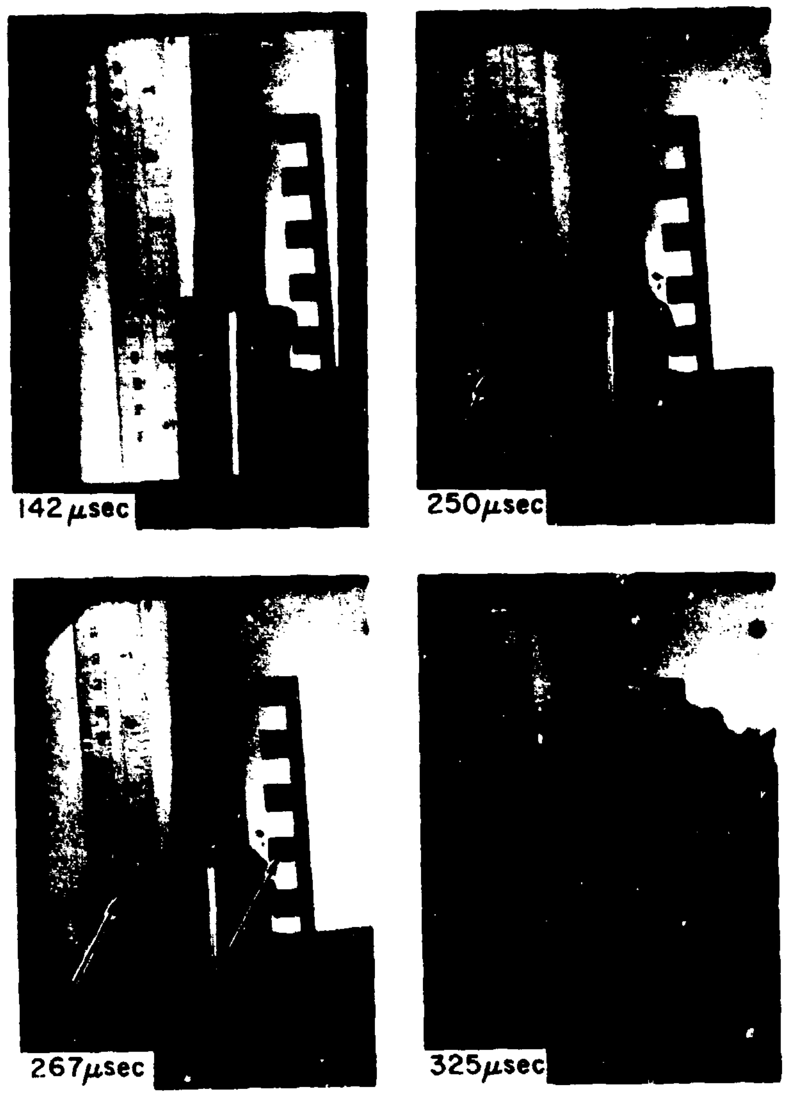

FIG. 3 LVD INITIATION IN LEAD TUBE

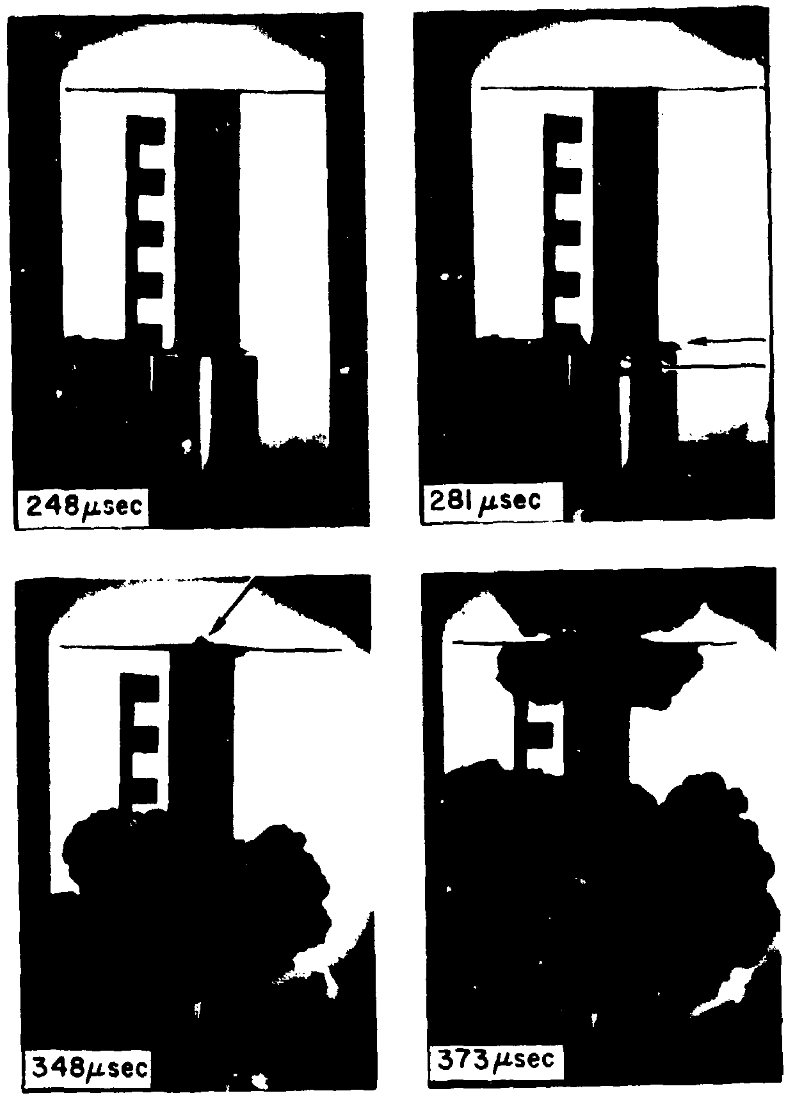

FIG. 4 LVD INITIATION IN STEEL TUBE WITH WITNESS PLATE

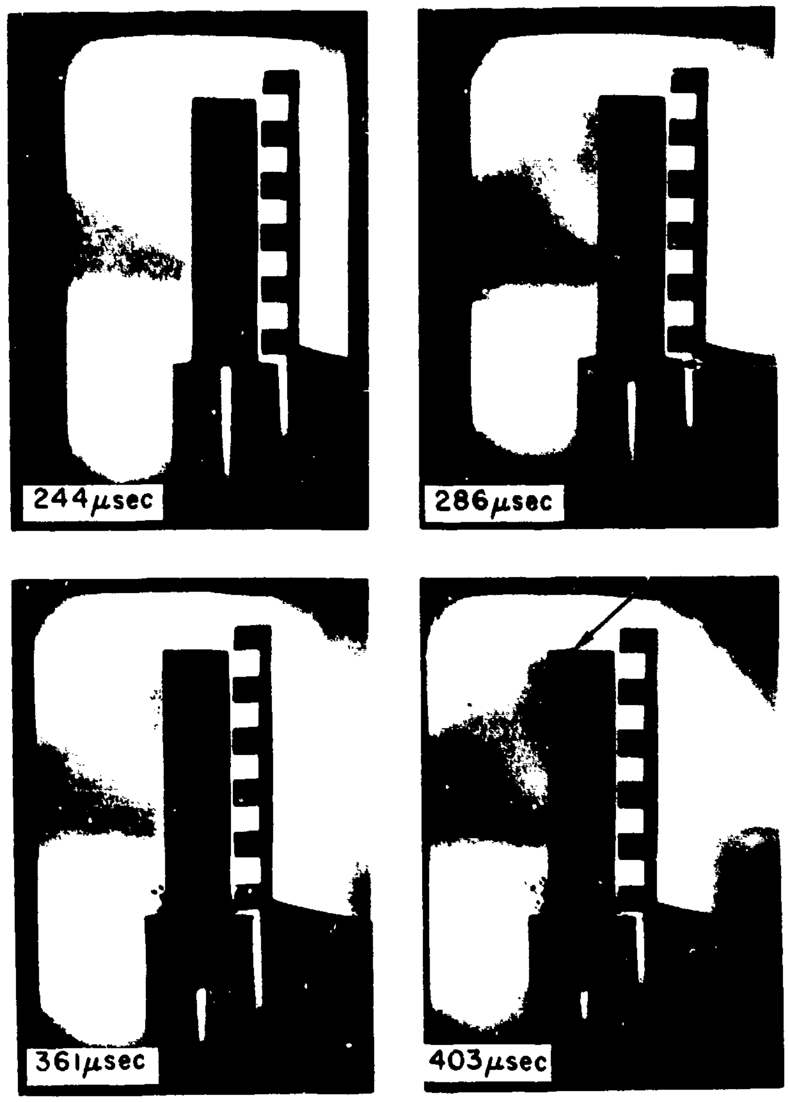

FIG. 5 LVD NON-INITIATION IN STEEL TUBE WITHOUT WITNESS PLATE

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Whitney, LCol R. L.	3rd Marine Aircraft Wg, El Toro, Calif.
Wiegand, W. W.	Rocketdyne Div, NorthAmericanAv, Canoga Pk, Cal.
Wigger, G. F.	Office, ChEngrs, DeptArmy, Washington, D.C.
Willis, F. M.	E.I. duPont deNemours & Co., Wilmington, Del.
Wilson, F. W.	NWS Seal Beach, Calif.
Wilson, P. D.	Pacific Missile Range, Point Mugu, Calif.
Winckler, L. E.	Rohm & Haas Co., Redstone ResLabs, Huntsville, Ala.
Wiuff, C.	Pace Corp., Memphis, Tenn.
Wood, R.	Indiana AAP, Charlestown, Ind.
Wright, F. C.	NOL White Oak, Silver Spring, Md.
Wright, H. W.	Twin Cities AAP, Minneapolis, Minn.
Young, R. E.	Picatinny Arsenal, Dover, N. J.
Zimmer, Dr. M. F.	NOS Indian Head, Md.

DEPARTMENT OF DEFENSE EXPLOSIVES SAFETY BOARD
2461 EISENHOWER AVENUE
ALEXANDRIA, VIRGINIA 22331-0600

DDESB-KMC

0 7 JUL 2000

MEMORANDUM FOR DDESB RECORDS

SUBJECT: Declassification of Explosives Safety Seminar Minutes

References: (a) Department of Defense 5200.1-R Information Security Program, 14 Jan 1997

(b) Executive Order 12958, 14 October 1995 Classified National Security Information

In accordance with reference (a) and (b) downgrading of information to a lower level of classification is appropriate when the information no longer requires protection at the originally level, therefore the following DoD Explosives Safety Seminar minutes are declassified:

a. AD#335188 Minutes from Seminar held 10-11 June 1959.
b. AD#332709 Minutes from Seminar held 12-14 July 1960.
c. AD#332711 Minutes from Seminar held 8-10 August 1961.
d. AD#332710 Minutes from Seminar held 7-9 August 1962.
e. AD#346196 Minutes from Seminar held 20-22 August 1963.
f. AD#456999 Minutes from Seminar held 18-20 August 1964.
g. AD#368108 Minutes from Seminar held 24-26 August 1965.
h. AD#801103 Minutes from Seminar held 9-11 August 1966.
i. AD#824044 Minutes from Seminar held 15-17 August 1967.
j. AD#846612 and AD#394775 Minutes from Seminar held 13-15 August 1968.
k. AD#862868 and AD#861893 Minutes from Seminar held 9-10 September 1969.

The DoD Explosives Safety Seminar minutes listed above are considered to be public release, distribution unlimited.

DANIEL T. TOMPKINS
Colonel, USAF
Chairman

Attachments:
1. Cover pages of minutes

cc:
DTIC

AD # 824044

MINUTES
OF THE NINTH
EXPLOSIVES SAFETY SEMINAR

NAVAL TRAINING CENTER

San Diego, California

15-17 August 1967

Sponsor

ARMED SERVICES EXPLOSIVES SAFETY BOARD

Washington, D. C. 20315

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